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[625 .145.3]

A contribution to the study of rail corrugation,

By CH. FRÉMONT.

Figs. 1 to 4, pp. 276 and 277.

(*Le Génie Civil.*)

In a previous article published in the *Génie Civil* on the investigation into the first beginnings of corrugated wear of rails ⁽¹⁾, I described the arrangement I had been led to devise for taking on a sheet of paper an impression shewing the distribution of the pressure on the surface of a rail during the passage of a wheel over it. Figure 1 shews the method of putting in place by means of a clip holder the thin sheet of paper, which will record the impression caused by the tram wheel running over it on the rail.

These records can only be taken in the streets in good weather and this is the reason for the delay in preparing this second article.

If the first beginnings of the deformation of the rail by corrugated wear are to be studied methodically, prints of the rail have to be taken at different periods of its service: first of all when newly laid, then when the first signs of corru-

gation are observed, and finally at intervals as the deformation of the corrugated surface becomes more marked.

In making this test, there is a danger of experimenting on a rail which will shew little or no corrugated wear, and, even if a suitable rail be selected, the time the experiment takes can be very long. To avoid this loss of time, I have found it better to reverse the order and to begin by taking impressions from a markedly corrugated rail, and subsequently to take further impressions from the same rail at the same place after the rolling surface has been filed up into good order.

Mr. Bacqueyrise, Director-General of the « Société des Transports en commun de la Région parisienne », has deeply interested himself in this investigation, and has enabled me to collect these rail impressions in the way described.

The operator takes care to so locate the site chosen that he may be able to take

⁽¹⁾ Number of the 13 November 1926 (vol. LXXXIX, No. 20, p. 425).

all the impressions at the *same position on the rail*. Figures 2, 3 and 4 are full size photographic reproductions of these impressions. Figure 2 is an impression taken on the rail the running surface of which has just been put into good order, during the passage of a wheel at a speed

of 17 km. (10.6 miles) an hour. Figure 3 is the impression taken under a wheel at a speed of 31 km. (19.3 miles) an hour. Figure 4 had been taken previously on *the rail which was very much corrugated* at a speed of 28 km. (17.4 miles) an hour.



Fig. 1. — Device for taking on a sheet of paper an impression shewing the distribution of the pressures on the surface of a rail during the passage of a wheel over it.

When these three impressions are first examined, it is noticed that the corrugation corresponds fairly closely: the distance between the summits of the waves is about 75 mm. (3 inches) which is equivalent for the distance travelled in an interval of time of the order of a *hundredth of a second*.

The impressions of the tread of the wheel are continuous in figures 2 and 3, whereas in the corrugated rail, the impression of figure 4 is interrupted at

about the ridges of the corrugations.

In the case of the impressions of figures 2 and 3, the width of the tread varies from 5.6 mm. ($\frac{7}{32}$ inch) to 6.5 mm. ($\frac{1}{4}$ inch) at a speed of 17 km. (10.6 miles) an hour (fig. 2) and from 4 mm. ($\frac{5}{32}$ inch) to 7 mm. ($\frac{9}{32}$ inch) at a speed of 31 km. (19.3 miles) an hour (fig. 3).

The minimum width which under these conditions is found with the minimum pressure of the wheel on the rail

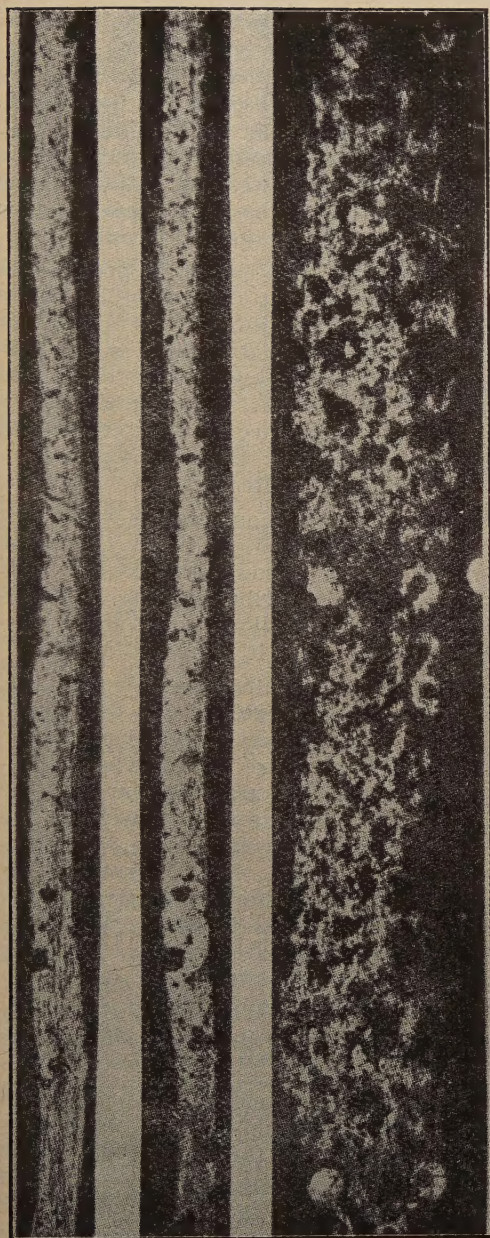


Fig. 2.—Impression
of wheel tread
on level rail.
Speed : 17 km.
(10.6 miles per hour).

Fig. 3.—Impression
of wheel tread
on level rail.
Speed : 31 km.
19.3 miles per hour).

Fig. 4.—Impression
of wheel tread
on much
corrugated rail.
Speed : 28 km.
17.4 miles per hour).
(Full size).

corresponds with the summit of the corrugation : the maximum width corresponds with the maximum pressure.

Now there are two different causes which can produce a *blow* of the wheel on the rail :

1. The oscillations of the body on the frame through the springs, the duration of these oscillations being of the order of about a half second;

2. The vibrations of the rail, the duration of which is of the order of about a hundredth of a second.

The great difference between these periods enables us without hesitation to ascribe the beginning of corrugated wear to the *vibration of the rail*, because the impressions record a period of sensibly the same magnitude as that of the rail vibrations.

The *hypothesis* of the vibration of the rail being the principal cause of corrugated wear was formulated by Mr. Dubs, Director of the Marseilles Tramways in his report to the International Congress of Milan in 1906.

Mr. Dubs, furthermore, explained the phenomenon of corrugated wear in the following manner :

« If the rail is vibrating quickly, the specific pressure and the degree of adhesion at the point of contact will necessarily vary in proportion to the amplitude of the vibration of the rail and at the same frequency.

» The tangential force at the point of contact remaining constant, variations in the degree of adhesion can result in a periodic acceleration or deceleration of the angular speed of the wheel. As the mass of the vehicle cannot instantaneously conform with these changes, a succession of *slips* ought to occur resulting in the corrugated wear of the rail. »

In this way, according to Mr. Dubs, the corrugated wear would be produced by *abrasion*, but this is only a theory, and its exactitude has not been demonstrated by any practical experience.

An inspection of the impressions (figs. 2 and 3) taken before there was any trace of corrugation, and whilst the rolling surface was perfectly level, enables us to explain from the distribution of the pressure on the rail what is the phenomenon first causing corrugated wear.

The vibrations of the rail, being of the order of a hundredth of a second, result in a *blow of the rail on the wheel*. The pressure of the wheel on the rail does not cease to act as the narrow bearing surface is continuous: the rail in vibrating strikes against the wheel, the intensity of the blow varying with the mass of the rail: a light rail gives a small blow, and a heavy rail a more violent shock. It is for this reason that the « fish-plated joint appears to reduce the corrugated wear and to an increasing extent as the mass at the joint becomes considerable ».

This phenomenon is proved by the fact that light rails, such as the Marsillon, are generally free from corrugated wear. It has been an error of interpretation to attribute this phenomenon not to the weight of the metal, but to the quality, supposed to be better as a result of the greater amount of work done to it during rolling.

When recording the pressure on the paper under the effect of the blow of the rail on the wheel, the axle tends to bend in the vertical plane, and the wheel to press more tightly on the edge of the paper nearer the centre line of the track.

Do successive vibrations of the rails become superimposed?

The two impressions (figs. 2 and 3) shew that the corrugations of this rail are superimposed because the impressions of small rust nodules, by which the position at which the impressions taken are located, can be noticed as recurring at their respective positions on the corresponding corrugations: this is not at all a matter of chance as the same fact is observed on other impressions taken at the same point under

carriages running at widely different speeds.

The reason the whole of the prints taken at the same place on the rail do not all shew similar impressions is that, owing to the cone of the tyre and to nosing action, the rolling surface of the wheel is not always the same distance from the edge of the rail head.

This first test makes it possible to state that at least in *certain cases* the successive vibrations of the rail do become superimposed, which is not surprising, as we know that under certain conditions such as, for example, when fish-plated joints are used the corrugated wear is reduced: the same cause produces the same effects.

When, on the contrary, they are not damped, the vibrations under the blows of the wheels reproduce themselves with an irregular distribution, the deformation of the rail follows suit: and consequently the wear is more uniform.

Where the vibrations exactly coincide, the waves are regular, and the corrugated wear appears very soon. When the vibrations are irregularly distributed, the waves are irregular and the corrugated wear appears slowly: in the extreme case in which there is a complete breaking up of the vibrations, the wear becomes uniform and general over the whole rolling surface. We ought then to endeavour to get this breaking down of the vibrations.

Between the two extremes, the whole possible range of this kind of wear is found:

The vibratory movement of the rail has generally been of small amplitude, and the blow of the rail on the wheel will also only cause corrugated wear of shallow depth. This is particularly the case on railways where the rails can readily yield elastically. This, above all, results in regularly maintaining the vibratory movement and gives rise to a more and more noticeable noise fre-

quently very annoying to both passengers and anyone near the railway.

In the case of tramway rails it is not so, as they are generally laid on a *hard and rigid bed*. The wheel on dropping into the bottom of the corrugation gives a blow which is the harder the heavier the rail and the more rigidly it is supported on the bearing. The rail and bearing act as the tup and anvil of a mechanical hammer. The mechanical work of the blow is not completely absorbed by an elastic deformation of the rail and the resulting maximum instantaneous effort crushes the rolling surface locally.

Herein is a second cause of the deformation of the rail considerably accentuating the corrugated wear because the blows increase rapidly in force, the drop of the wheel becoming greater and greater.

In addition, during this period of corrugated wear, there is no irregular distribution possible as during the period of corrugated wear due to the vibration of the rail.

The print (fig. 4) shows the band bearing on the rail the corrugated wear of which is at the practical limit allowed that is to say, at the time the rail has to be repaired by doing up the rolling surface.

Work hardening over a slight depth has made the steel very hard and in consequence the wheel falling into the bottom of the corrugation bounces out and passes over the ridge almost without touching it.

The strength of the steel of the rail therefore depends upon the value of the elastic limit of the metal, not only on the initial limit of elasticity, that is to say, of the rail as new, but also on the limit of elasticity increased by cold working at every period of its service.

Selection of steel for tramway rails. — Corrugated wear not being entirely avoidable in our present state of knowledge, the problem is to know what steel

will best stand up against wear of this kind.

We have seen that there are two kinds of wear: one produced by the wheel slipping and causing *abrasion* of the metal, and the other produced by deformation under shocks which cause a local *crushing*.

The whole of the authors I have had occasion to consult unanimously admit only the wear by *abrasion*. My experiments shew me that with few exceptions it is the wear by crushing that causes corrugation, as I have just demonstrated.

Certain authors, in particular it seems, the Americans, Messrs. Robin and Dudley, accepting the general opinion that the corrugated wear of rails is caused by abrasion, have suggested a minimum *elongation* for the test pieces of rail steel tested for tensile be imposed. They have evidently taken the idea from the remark I first made in 1916 in my 49th pamphlet entitled: *The File* (p. 104) (1) that the quantity of work done in filing a steel is increasingly great as the steel becomes more ductile.

This is however a fundamental error: that is, in taking the ductility of a steel as being measured by the elongation obtained by the usual method of measuring the distance between two gauge points.

The value of the ductility is given by comparing the area of the smallest section, the minimum drawn down section at rupture, with the initial area.

The steel offering the greatest resistance to abrasion, according to this theory, ought to be requisitioned particularly in the case of rails in which the vertical face of the groove is worn by a kind of *filing action* of the wheel flange.

As I have shewn, however, the corrugated wear of the rolling surface of the rail is produced by a continued hammering action, and it becomes necessary to use a steel which resists crushing. This

(1) This pamphlet has been analysed at length in the *Génie Civil*, 31 March 1917 (vol. LXX, No. 13, p. 201).

steel is one which gives the highest limit of elasticity, not only when new, but also during its whole life until it is completely worn out.

In a paper before the *Académie des Sciences*, on the 1 March 1920, I pointed out this fact: « I have had to note as a result of some tensile tests made on rails, some worn after short service, and others, on the contrary, after long service, that the *final tensile strength* had some part in the resistance to wear. »

The ultimate tensile strength therefore ought to be included in the Specification for rails ⁽¹⁾. It should be noted that

⁽¹⁾ Ch. FRÉMONT, 69th pamphlet: *Wear and defects of rails*, Paris, 1924, pp. 13 to 26.

the ductility and the ultimate tensile strength of a steel are not necessarily opposed, although they are different.

CONCLUSION. — I have endeavoured to ascertain *experimentally* the cause of the corrugated wear of rails, but the equipment of my simple laboratory does not allow me to carry the investigation further.

I understand, however, that investigations are being continued abroad on a test section of line on which two rails can be fitted with all known equipment which may set up vibration. Furthermore, recording instruments are used so that the investigator may have full information during the whole of the tests.

[625 .145.5 (.75) & 656 .281 (.75)]

Interstate Commerce Commission (U. S. A.).

Report of the Director of the Bureau of Safety in re-investigation of an accident which occurred on the St. Louis-San-Francisco Railway near Victoria, Miss., on 27 October 1925. ⁽¹⁾ ⁽²⁾

Figs. 1 to 55, pp. 283 to 337.

16 June 1927.

To the Commission :

On 27 October 1925, there was a derailment of a passenger train on the St. Louis-San Francisco Railway near Victoria, Miss., which resulted in the death of 20 passengers and 1 employee of the railroad and the injury of 117 passengers, 8 Pullman employees, 3 mail clerks, and 2 employees of the railroad. The investigation of this accident was

made in conjunction with a representative of the Mississippi Railroad Commission.

Location and method of operation.

This accident occurred on the Tupelo subdivision of the southern division, extending between Memphis, Tenn., and Amory, Miss., a distance of 126.8 miles. This was a single-track line over which trains were operated by time-table and train orders, no block-signal system

⁽¹⁾ Preparation of report delayed on account of large amount of research work occasioned in obtaining the necessary data.

⁽²⁾ See previous articles on the same subject in the *Bulletin of the Railway Congress*, August 1926 number, pp. 694 and 696, and August 1927 number, p. 665.

being in use. The point of accident was 1 351 feet south of the station at Victoria; approaching this point from the south the track was tangent a distance of 2 387 feet, with a descending grade for northbound trains of 1 %.

The track was laid with 90-pound rails, 33 feet in length, with an average of 20 treated red-oak ties to the rail length, tie plated and single spiked, and ballasted with about 12 inches of slag. The general maintenance of the track was good. At the point of accident the track was on a fill about 11 feet in height, while 506 feet north of the point of accident there was an eight-panel pile trestle.

The weather was clear at the time of the accident, which occurred between 6.35 and 6.40 a. m.

Description.

Northbound passenger train No. 108 consisted of 1 refrigerator express car, 1 combination mail and baggage car, 1 baggage car, 2 coaches, and 7 Pullman sleeping cars, hauled by engine 1060, and was in charge of Conductor Ryan and Engineman Herring. The fifth car was of wooden construction, the first, second, third, and tenth cars were of steel-underframe construction, and the others were of all-steel construction. This train left Holly Springs, 12.4 miles south of Victoria, at 6.20 a. m., five minutes late, and was approaching Victoria when it was derailed while traveling at a speed estimated to have been between 40 and 50 miles per hour.

The engine and tender were not derailed, but broke away from the cars and finally were brought to a stop at a point 2 118 feet north of the initial point of accident. The first 10 cars and the forward truck of the eleventh car were derailed, all the derailed equipment going to the left of the track. The first car passed over the trestle and came to rest on its left side about 735 feet north of the initial point of accident, and the

next two cars were bottom up opposite the trestle. The fourth and fifth cars came to rest on their right sides, with the sixth car on its left side, while the next four cars remained nearly upright, leaning toward the left. The employee killed was the conductor.

Summary of evidence.

Engineman Herring estimated that his train was approaching Victoria at a speed of 45 or 50 miles per hour when he felt the air brakes apply as if a hose had parted. He had not noticed any jar which might have resulted from passing over a broken rail, and he said that he did not make any investigation for the purpose of ascertaining the cause of the accident. The statements of Fireman Young brought out nothing additional of importance. Flagman Fleming went back to protect his train, and he also stated that he did not make any investigation into the cause of the accident.

The engine and train crews of northbound extra 4012, the last train to pass over this section of track prior to the occurrence of the accident, said that at that time they did not notice anything wrong with the track.

Examination of the track developed the fact that the first mark of derailment was at the point where a rail had broken on the left or west side of the track. The initial fracture was located 13 ft. 8 3/4 in. from the receiving end of the rail and the surfaces of the fracture showed the presence of a well-defined transverse fissure on the gauge side of the head of the rail. This fracture at one point extended to within one thirty-second of an inch of the surface of the rail, and its appearance indicated that air had reached it, the metal having been oxidized; north of this initial fracture the rail was broken into several pieces. The examination of the track did not indicate that there was anything else wrong with it, nor was there any evidence of dragging equipment, while care-

ful examination of the engine failed to disclose anything wrong. The coupler had pulled out of the head end of the first car. Engineman Herring said this coupler was lying on the track near the switch opposite where the first car came to rest, and it is not considered that the pulling out of this coupler had anything to do with the accident.

This accident was caused by a broken rail, the examination of which was made by Mr. James E. Howard, engineer-physicist, whose report follows. It was the most serious one due to a transverse fissure which has occurred since the accident at Manchester, N. Y., on the Lehigh Valley Railroad on 25 August 1911, when this type of fracture was first brought to general notice in a report of the Interstate Commerce Commission.

A transverse fissure is recognized as the most dangerous type of fracture en-

countered in railroad service. Transverse fissures are appearing in the track in numbers which are very disquieting. The physical reasons for their display seem explainable. Means for their prevention under current traffic have not been found.

The engineer-physicist has added to the report upon the rail which was the cause of the present accident remarks upon physical properties inherent to different steels, in review of the general subject of transverse fissures, extending the remarks to other types of rail fractures. The conditions which tend to cause, the display of transverse fissures are present in all rails. The specific reasons for their occurrence are more clearly presented in this comprehensive review.

Respectfully,

W. P. BORLAND, *Director.*

Report of the engineer physicist.

The derailment of passenger train No. 108, near Victoria, Miss., on 27 October 1925, was caused by a broken rail which displayed a transverse fissure at its initial point of rupture. This fracture was located 13 ft. 8 3/4 in. from the receiving end of the rail. From this point to the leaving end the rail was broken into not less than nine pieces. Four additional partially developed transverse fissures were displayed by these fragments.

The broken rail was located on the left side of the track, with reference to the direction the train was traveling. The rails from both sides of the track were torn up for a distance of about 340 feet. Beyond the opening thus made the track was not seriously damaged.

The circumstances attending the derailment were doubtless as follows: The initial fracture of the broken rail probably occurred under the wheels of the engine. The track structure remained serviceable for a short time, allowing the

engine, tender, and three cars of the train to pass over it in safety. The leaving end of the rail soon began to break up and was successively broken into short fragments. Through this opening the middle part of the train was derailed and the track structure then destroyed for a distance of 340 feet.

The engine and tender kept on the rails, in advance of the destroyed section, and came to rest at a distance of 2 118 feet beyond the initial break. The last car of the train came to rest before it reached the place occupied by the broken rail. Cars of the forward end of the train were dragged over the westerly side of the track. The fifth car, a day coach, and the sixth car, a Pullman sleeper, were jammed together, each being badly damaged. Four of the rear Pullman sleepers were partially overturned, while two remained upright on the track.

Figure 1 is a plan of the track taken from a blue print from the office of the

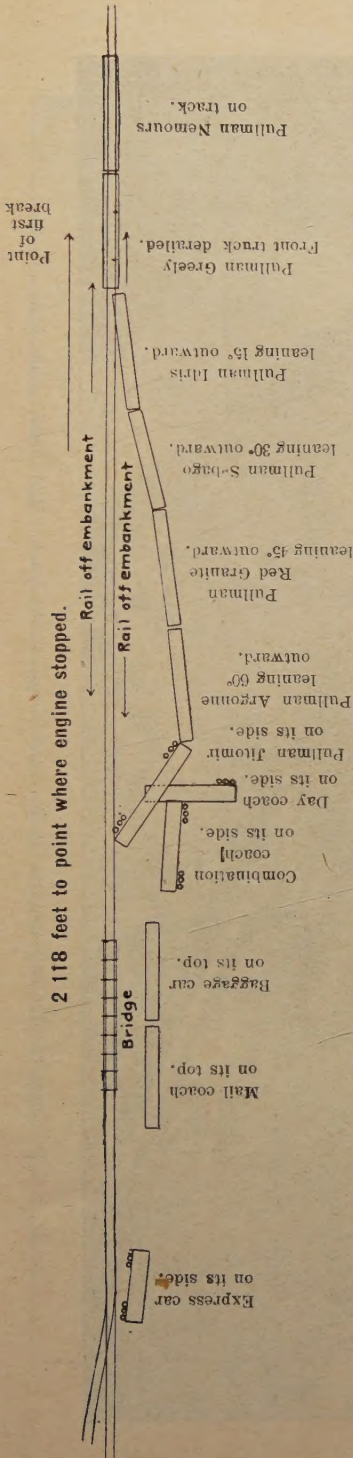


Fig. 1. — Plan of the track showing positions occupied by the derailed cars.

division engineer of the railroad. It shows the first car of the train on its side; the second and third cars bottom side up; the fourth car on its side; the fifth and sixth cars, a day coach and a Pullman sleeper, jammed together. Four Pullman sleepers, next in order, leaned outward at different angles, while the last two Pullman sleepers remained in upright positions. The car next the last one of the train spanned the broken rail, its forward truck derailed, its rear truck on the rails.

The rails from the west side of the track were broken or detached from each other. Nine rails of the east side of the track remained attached to each other, their splice bars unbroken. These nine rails were ploughed off the ties and thrown from the roadbed out on to the highway paralleling the track. They formed a large loop which extended at its farthest point 75 feet from their position in the track. They were bent side-wise, some convex on the gauge side, others concave. Figure 2 illustrates the positions occupied by these nine rails after the accident. They were thrown from the track with such force and suddenness that the loop was made in the air and fell almost vertically upon the highway.

Figure 3 is a view of the first Pullman sleeper, the Jitomir, showing the manner in which the middle part of its length crushed the rear end of the day coach.

Figure 4 shows the derailed Pullman sleepers, Sebago, Red Granite, Argonne, and Jitomir, respectively.

Figure 5 is a drawing of the rail which broke and caused the accident. It weighed 90 pounds per yard, was rolled by the Tennessee Coal, Iron & Railroad Company, in the month of October, 1918, and was laid in the track in April 1919. It had been in service, therefore, 6 years and 6 months. It was branded O. H. Tennessee A. S. C. E. 9040 10 1918. Heat number 17054, ingot letter C.

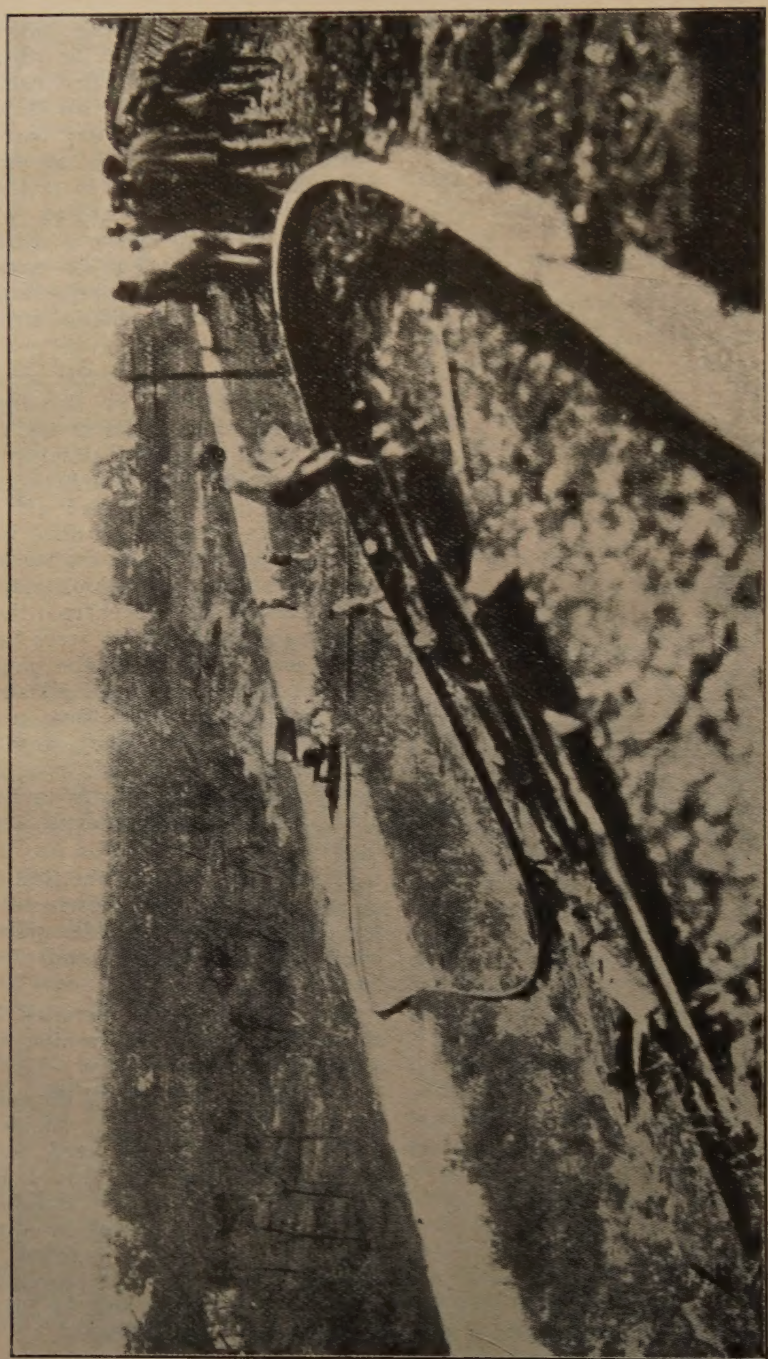


Fig. 2. — Loop made by nine rails plowed off the easterly side of the track. Rails bent, splice bars unbroken.

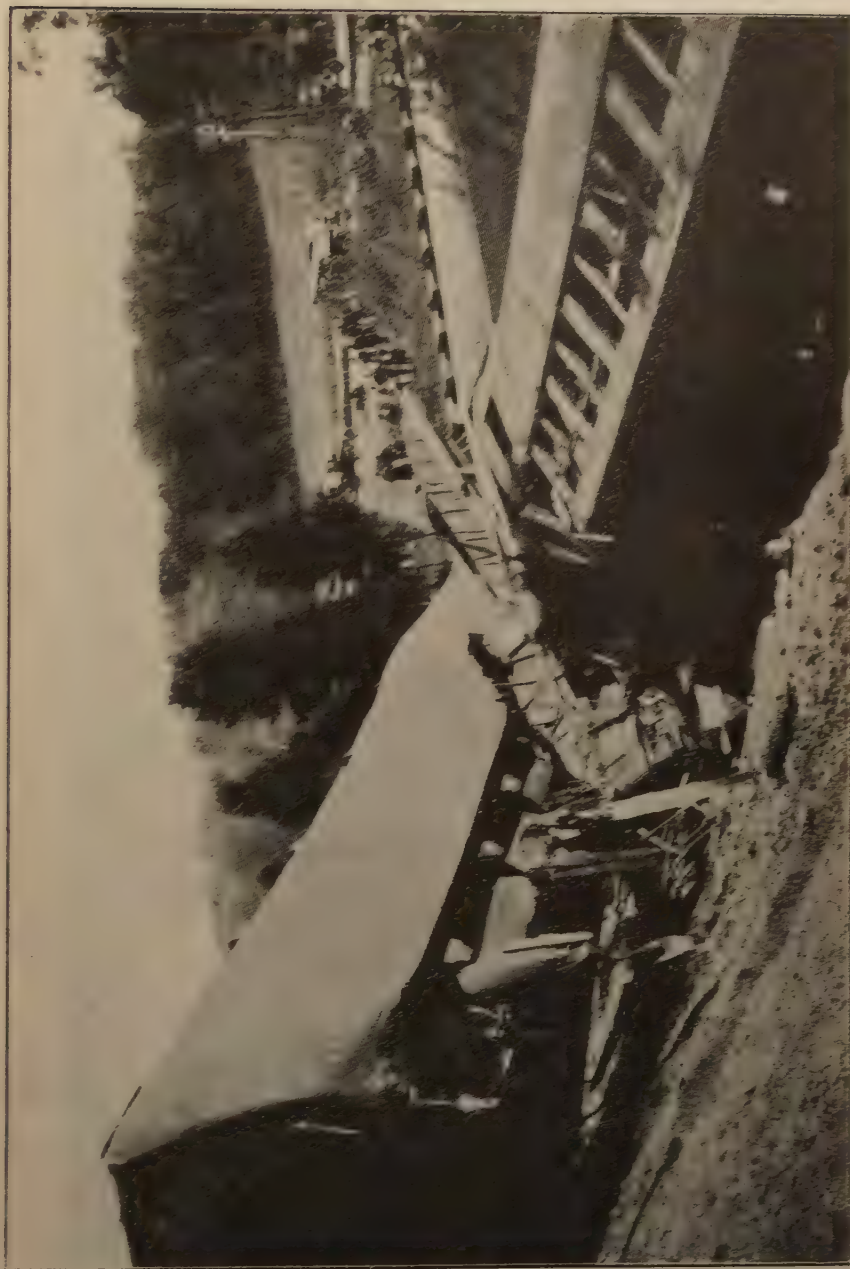


Fig. 3. View of the Pullman sleeper the Jilomir and a day coach. Middle of Pullman sleeper and end of day coach jammed together.



Fig. 4. — View of the derailed Pullman sleepers Sebago, Red Granite, Argonne and Jitomir, respectively.

There was a transverse fissure at the first break in the rail which measured $1 \frac{13}{16}$ by $1 \frac{7}{16}$ inches. The surfaces were darkened, indicating the fissure

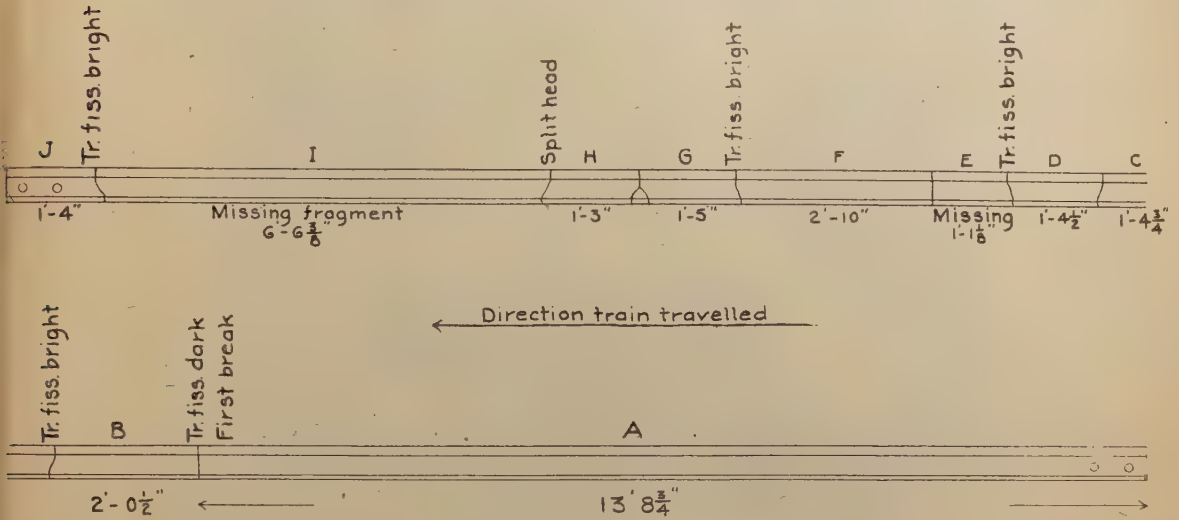


Fig. 5. — Drawing of the rail which caused the accident, showing location of fractures made in the track.
Rail branded O. H. Tenn. A. S. C. E. 9040 10 1918. Heat number and ingot letter 17054 C.

had reached the periphery of the head and air had been admitted prior to the accident.

For convenience of reference the fragments of this rail are designated by letters of the alphabet. The first break was between fragments A and B, which displayed the transverse fissure above described. Four additional transverse fissures were displayed at the time of the accident, the positions of which are indicated by figure 5. Each of these showed bright surfaces with a silvery luster. None of these four had reached the surface of the head prior to the accident. Subsequently a hammer test of fragment A revealed two more transverse fissures, making in all seven in this rail.

Figure 6 illustrates the appearance of the opposite faces of the transverse fissure at the first break in the rail. The section on the left of the cut represents the leaving end of fragment A; the section on the right, the receiving end of fragment B. This transverse fissure

covered more than one-half the cross section of the area of the head. The nucleus of the fissure was located on the gauge side of the head, not quite half way down its depth.

Figure 7 shows the appearance of one of the additional transverse fissures found in fragment A under the hammer test. Its bright silvery luster will be noted, a characteristic feature of transverse fissures before air is admitted to them. Its nucleus is on the gauge side of the head, in common with all others of this rail.

The manner of conducting the hammer tests was to place the rail, head down, on supports at the edges of the anvil and strike the rail on the base midway the supports, repeating the blows at short intervals along its length. Continuing the hammer tests, other rails were examined which came from the destroyed section of the track. Eleven rails were tested, five of which had the same heat number as the rail which first



Fig. 6. — Appearance of the opposite faces of the transverse fissure first to break.
Leaving and receiving ends, respectively, of fragments A and B.

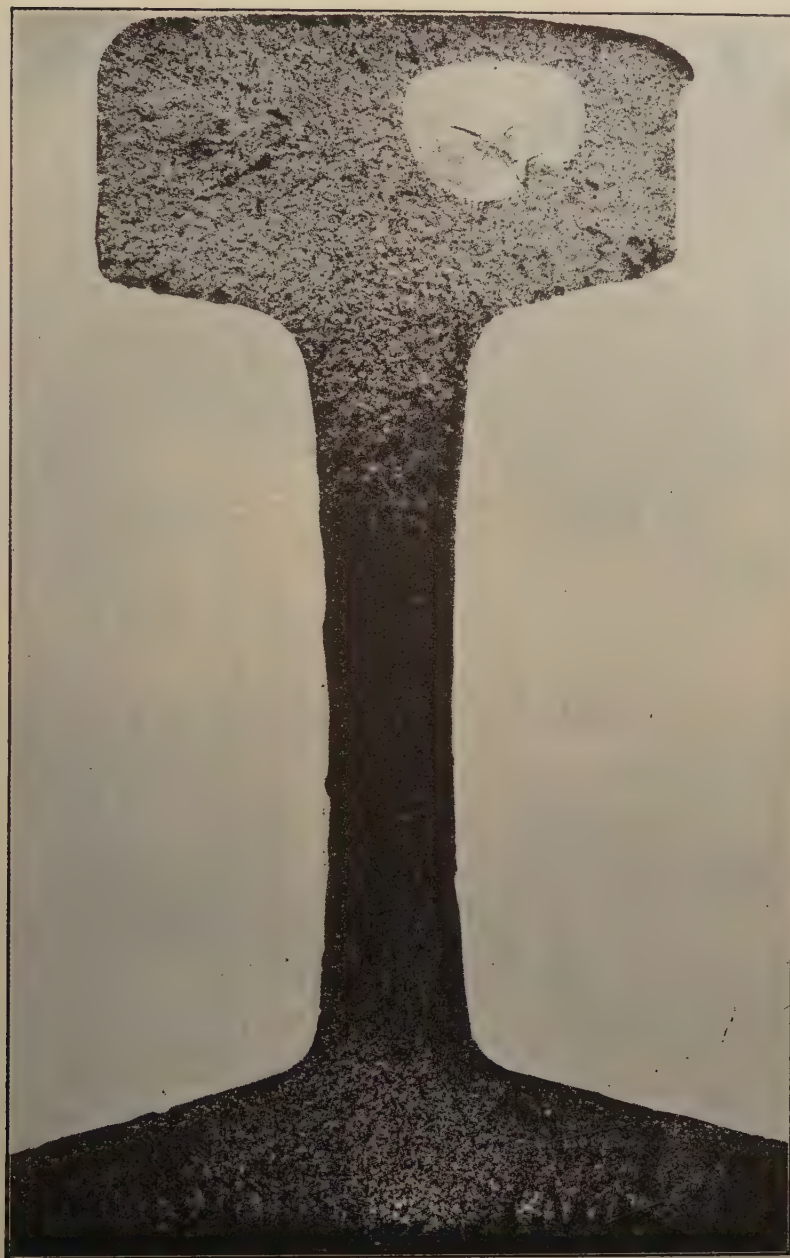


Fig. 7. — Partially formed transverse fissure revealed by hammer test of fragment A.

broke but different ingot letters. Six had different heat numbers but were of the same year's rolling, that is, 1918. Two short pieces of curve-worn rails were included in this examination which were not involved in the derailment. They had been used in rerailing the cars.

One of the objects of the hammer tests was to ascertain the condition of rails in the vicinity of the accident, whether transverse fissures were generally prevalent in that locality. One other rail, besides the rail first to break, displayed a transverse fissure in the track. In this rail three additional fissures were found,

which measured 1/4, 3/16 and 7/16-inch diameters, respectively. This rail had the same heat number as the rail which first broke, but with the ingot letter F. None of the other rails displayed transverse fissures.

Two pieces of the curve-worn rail were tested. Five fractures were made with the first piece, each brittle fractures and each starting at the corner of the head, gauge side. The second piece was annealed before testing. Its toughness was restored, resisting the hammer blows without rupture.

Mill analyses of the heats represented by these rails were as follows :

Heat.	Rolled.	C.	Mn.	P.	S.	Si.	Remarks.
17054	30 Oct. 1918	0.71	0.87	0.028	0.035	0.103	Rail of this heat caused the accident.
76990	29 Oct. 1918	0.63	0.77	0.030	0.029	0.127	
76995	30 Oct. 1918	0.66	0.71	0.028	0.034	0.165	
79997	30 Oct. 1918	0.69	0.80	0.026	0.036	0.120	
72569	12 Feb. 1914	0.63	0.87	0.034	0.037	0.116	Curve-worn rail.
20690	3 Dec. 1910	0.69	0.75	0.022	0.021	...	

Rail of heat number 20690 represented a transverse fissured rail, 85 pounds weight, which caused a derailment on the Southern Railway on 2 August 1925. In this accident the engine and tender passed over the broken rail successfully, the cars which followed being derailed. The age of this rail was 14 years, 4 months.

Check analyses of heat 17054, made in the laboratory of the St. Louis-San Francisco Railroad at Springfield, Mo., confirmed the mill analysis. At Springfield chips were taken from rails of ingot letters C and F, at two places on each, in line longitudinally with the transverse fissures which they displayed, and at corresponding places on the opposite side of the head. The composition was practically the same in each rail and at each place.

Prior to taking out chips for chemi-

cal analysis, the micro structure of rails 17054 C and F was developed by picric acid etching, the results being shown by figures 8 and 9. Substantially the same structure was displayed by each, with no peculiar characteristic in the vicinity of the transverse fissures.

Fragment F of rail 17054 C, figure 5, was used in an examination of the structural state of the steel at different depths below the running surface of the head. The metal was planed off in successive stages and the rail pickled in hot hydrochloric acid at each stage. Figure 10, *a*, *b*, *c*, and *d* are photographic views of the pickled surfaces at depths of 1/2, 5/8, 3/4, and 7/8 inch, respectively. The surface was clear at a depth of 1/2 inch. A few crosswise cracks appeared at 5/8-inch depth. Again the head was nearly clear at 3/4-inch depth. At 7/8-inch depth numerous cracks appear-

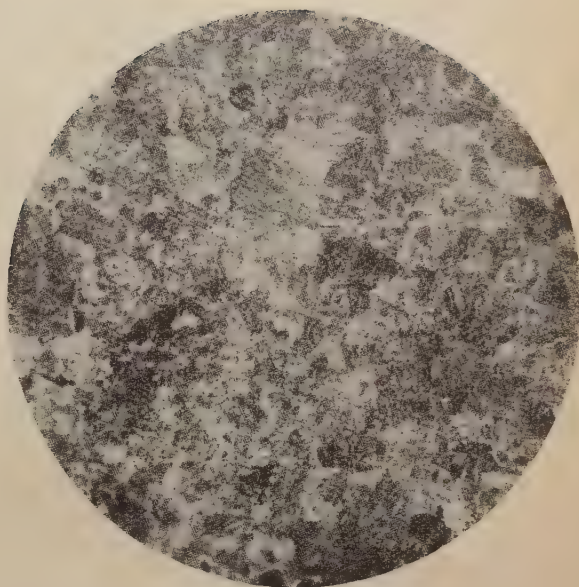
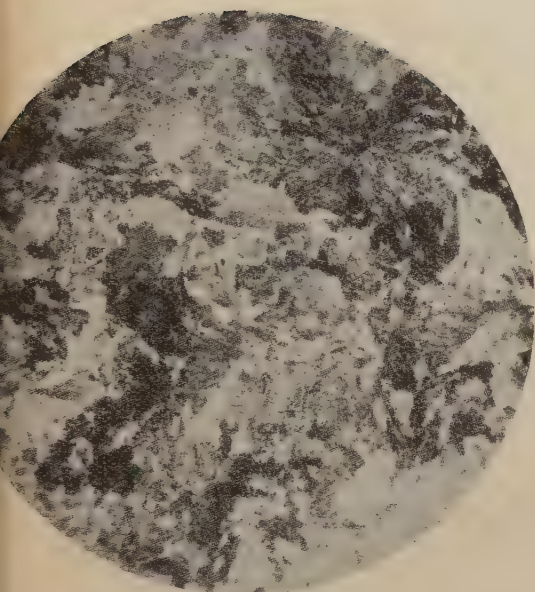


Fig. 8 — Microstructure of rail 17054 C, zone of transverse fissure and opposite side of head.
Magnification 100 diameters.

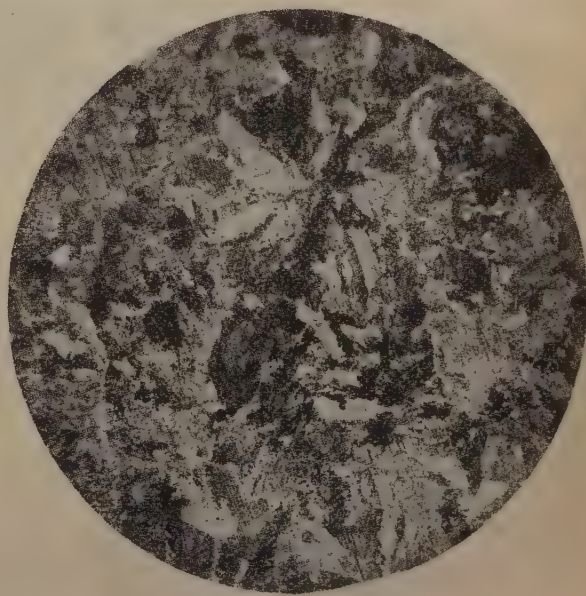
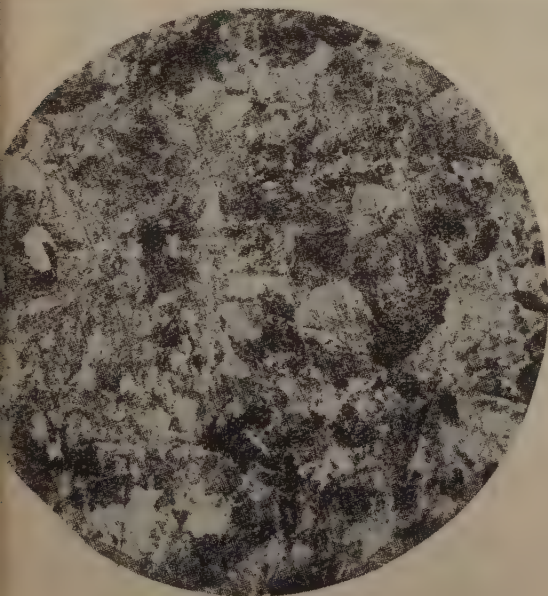


Fig. 9 — Microstructure of rail 17054 F, zone of transverse fissure and opposite side of head.
Magnification 100 diameters.

ed on the pickled surface. The nuclei of transverse fissures are seldom located so far down as the surface last pickled.

Pickling tests were made with fragment C, of figure 5. At a depth of 1/4 inch the surface was clear. At 3/8 inch down two short oblique cracks were displayed. At increased depths the pickled surfaces showed pronounced markings. Figure 11, *a*, *b*, and *c* show the appearance of the flaky metal encountered at depths of 1/2, 5/8, and 3/4 inch, respectively. The structure of the rail showed horizontal laminæ. It is understood, of course, that pickling puts some of the metal into solution, and that prolonged exposure in the bath greatly exaggerates the markings which represent the structural state.

The head of rail 17054-F was planed off and pickled. Figure 12 shows its appearance at a depth of 5/8 inch. The characteristic feature here is the presence of several incipient transverse fissures and a shattered zone on the gauge side of the head, with the central core nearly free from these manifestations. These markings are chiefly outside the zone of shrinkage cracks, and from their position would seem attributable to the action of wheel loads only.

Figure 13 illustrates the pickled surface of a 130-pound rail from the Baltimore & Ohio Railroad, planed off to a depth of 3/4 inch. Incipient transverse fissures are displayed in echelon from the gauge side of the head in steps toward the middle of its width. The short longitudinal cracks shown are believed to represent acicular slag streaks.

Figure 14 illustrates the presence of an incipient transverse fissure in a rail from another source. It represents an incipient fissure on the gauge side of the head of a 105-lb rail, from the New York Central Railroad. This rail displayed a transverse fissure in service. The head was planed off to the depth of the nucleus of the adjacent fissure and pickled, showing no shrinkage cracks. A duplicate specimen also showed clear

metal, that is, no zone of shrinkage cracks.

The examination of the rail responsible for the present accident and other rails from the section of destroyed track displayed no feature uncommon in the tests of other rails. Two rails of the same heat displayed transverse fissures. Others rolled the same month and year and having practically the same chemical composition neither showed transverse fissures in the track nor in the tests subsequently made in quest of them. No reason has been established why fissures were displayed in some parts of these rails and not in other parts; nor why the rails on one side of the track should display transverse fissures while those on the opposite side were exempt from their formation. The problem apparently is one of durability in respect to the endurance of complicated track stresses, concerning which indexical features pertaining to primitive properties, or structural state of the rails, have not been established by means of which the approach of rupture may be recognized or predicted when it will take place under given conditions of exposure.

Review of the subject of transverse fissures.

This occasion seems opportune to review the general subject of transverse fissures, referring to the time when first recognized as a distinct type of rail fracture, their early appearance and the increased number of examples which have since been reported, together with the explanation of their occurrence, and the reason why fractures of interior origin and development take place in the heads of rails.

A transverse fissure, as a distinct type of rail fracture, was first brought to notice in the report of the Interstate Commerce Commission on the accident of 25 October 1911, on the Lehigh Valley Railroad at Manchester, N. Y. A frac-

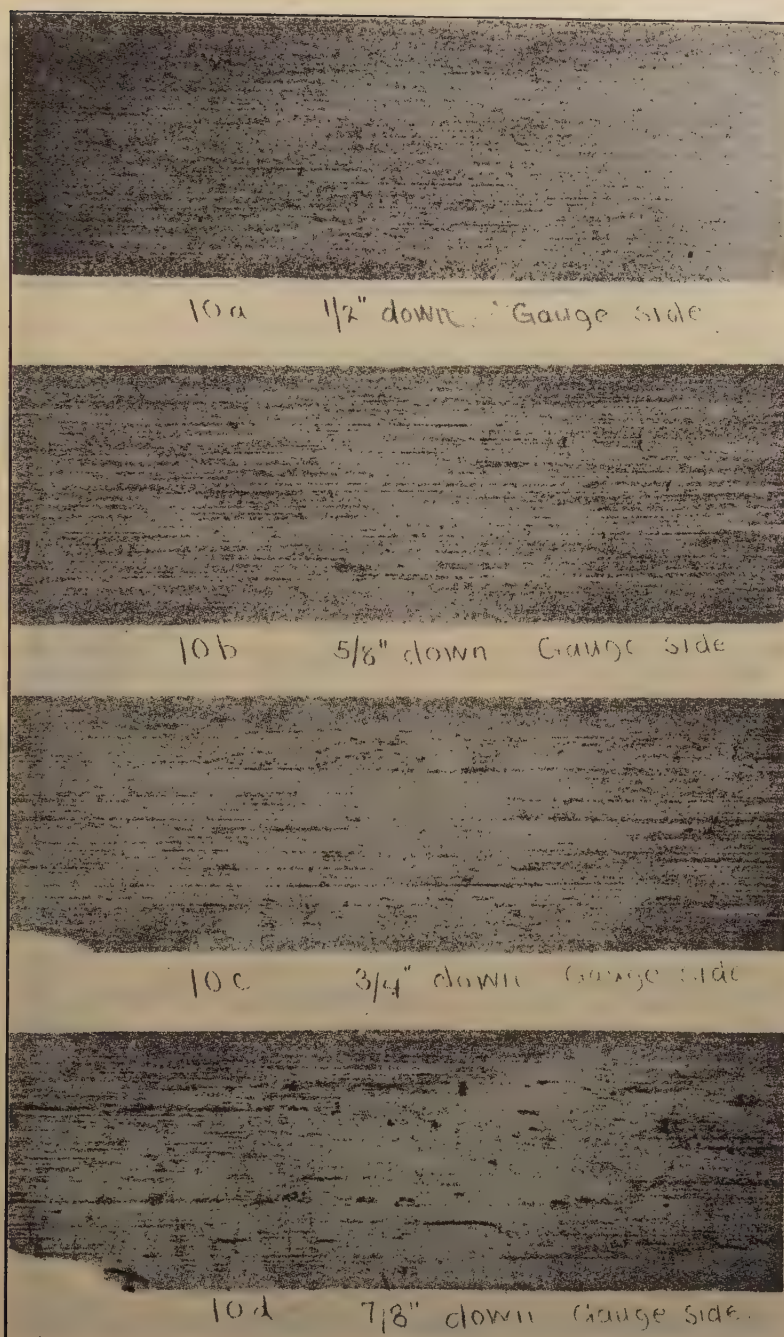


Fig. 10. — Head of rail 17054 C, fragment F, planed off in successive stages; surface pickled at each stage.

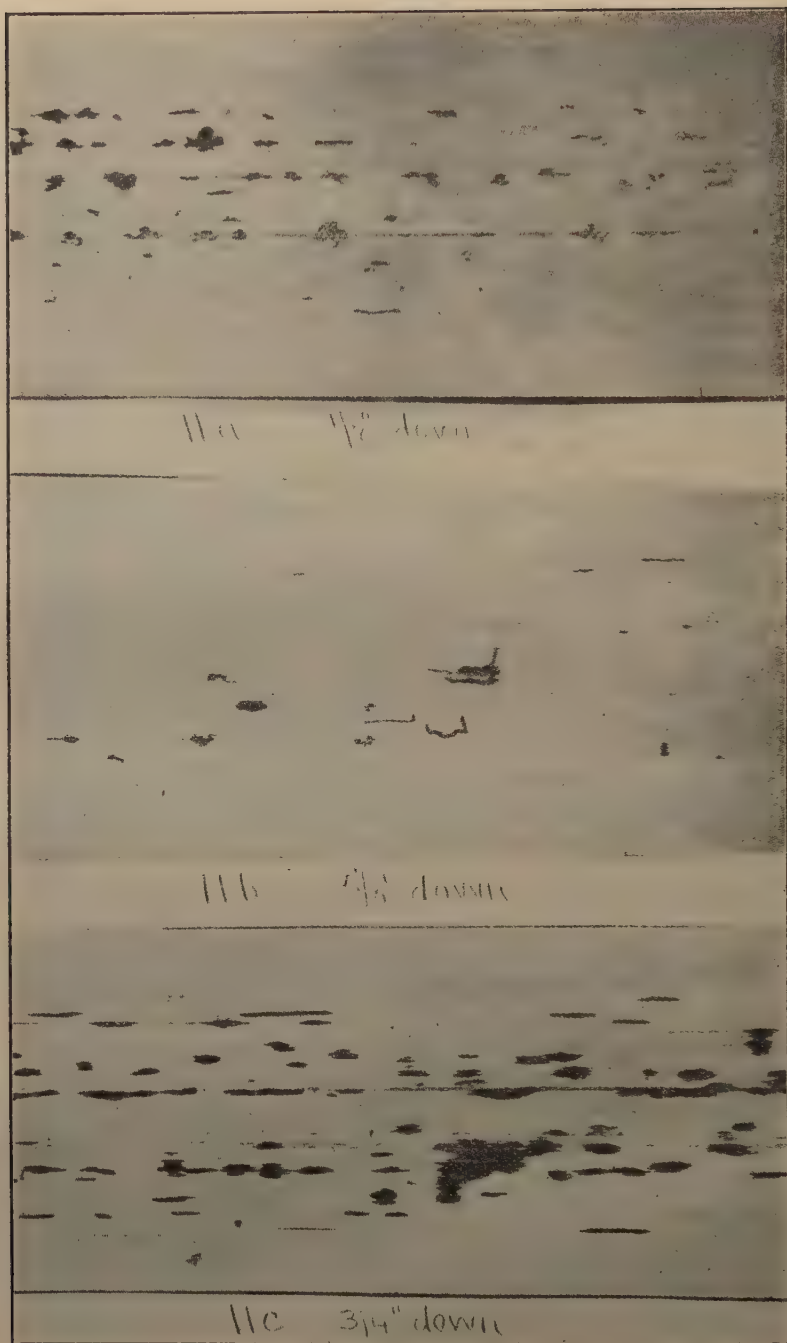


Fig. 11. — Head of rail 47054 C, fragment C,
planed off in successive stages; surface pickled at each stage.

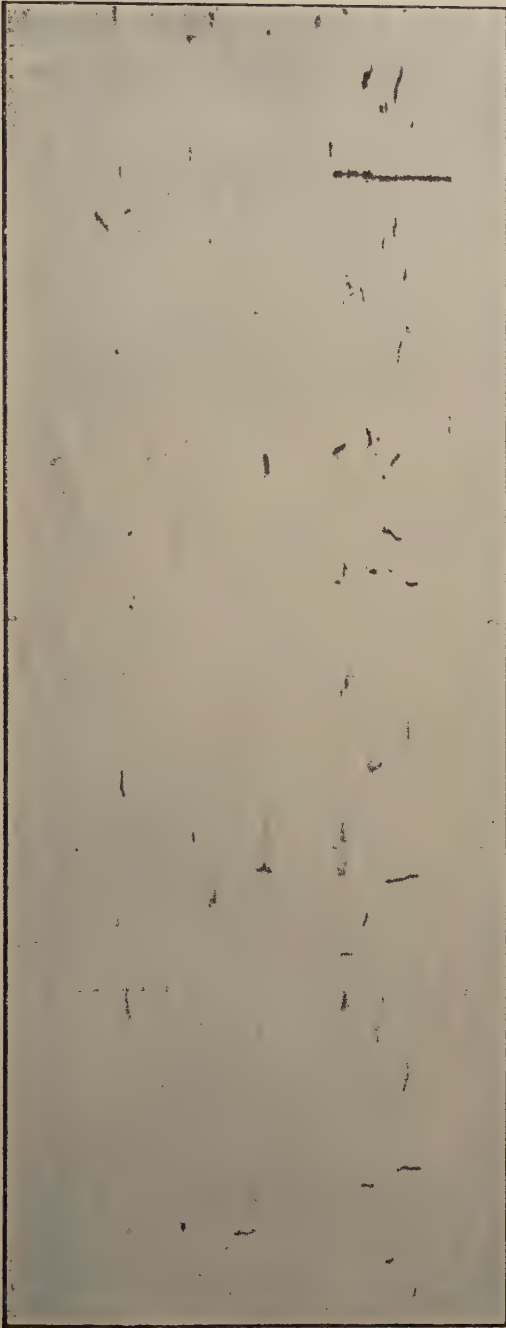


Fig. 12. — Head of rail 17054 F, planed off $\frac{5}{8}$ inch and surface pickled.
Incipient transverse fissures and shattering cracks located on gauge side of the head.

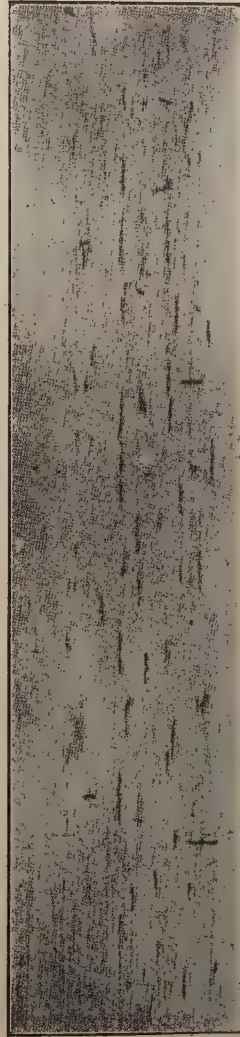


Fig. 13. — Head of 130-pound rail planed off $\frac{3}{4}$ inch and surface pickled.
Incipient transverse fissures from gauge side inward, also longitudinal slag cracks.

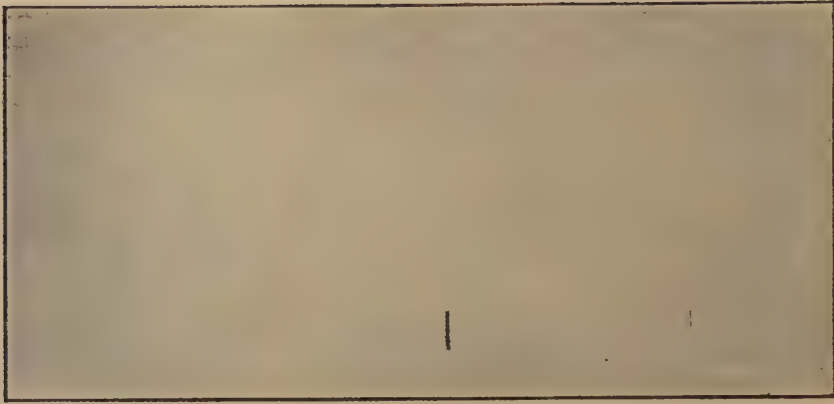


Fig. 14. --- Head of a 105-pound rail planed off to depth of nucleus of a transverse fissure displayed in the track, surface then pickled.

Incipient transverse fissure revealed on gauge side of the head. Surface elsewhere clear.

ture was there displayed in the head of the rail of interior origin. The metal of the head was partially separated in a vertical plane at right angles to the axis of the rail. It was a tensile fracture, in which the metal had yielded to longitudinal forces.

As one of interior formation it was recognized that such a fracture was caused by the action of some component which had not hitherto been taken into consideration as a factor in the rupture of rails. Under bending stresses, as a beam, the greatest range in fiber stresses is found in those elements most remote from the neutral axis of the rail, in the extreme fibers at the top or the bottom of the rail. In the display of transverse fissures those extreme fibers remain unruptured, while elements exposed to only a fraction of the maximum bending range were those which first ruptured. The action of an independent longitudinal force was necessary to account for this fracture of internal inception and growth. Familiarity with the effects of the cold-rolling action of wheels in setting up internal strains of compression in steel at once pointed to the necessary

component and thus explained the *raison d'être* of a transverse fissure.

A zone of metal at the top of the head acquires a state of internal compression from the impinging pressures of the treads of the wheels on the running surface of the rail. These internal strains of compression are counteracted and balanced by strains of tension set up in the interior of the head. Transverse fissures have their origins in this interior zone of metal. This explanation of the development and display of an interior fracture, based upon a law of physics that tensile fractures must occur in zones exposed to tensile strains, and can not occur in zones in a state of compression, was so self-evident and axiomatic that no extended remarks were offered in the original report on this type of fracture.

Among those familiar with the treatment and the working of metals the presence of internal strains and their possible culmination in rupture are matters of common knowledge. Great care is ordinarily exercised that such influences do not attain destructive limits. Outside of such circles a limited degree of atten-

tion has been given this important branch of the physics of steel.

The early reception of the announcement of a transverse fissure, a fracture forming within the head of a rail, was one of doubt or denial. Several years elapsed after the publication of the report on the Manchester accident before general and serious attention was given this type of fracture. So vague were the impressions entertained by some engineers that a large number of new rails were broken in quest of transverse fissures, with, of course, negative results. The transverse fissures displayed in the Manchester accident each covered a large part of the cross section of the head of the rail, which circumstances themselves would indicate the futility of a search directed upon new rails. Following these immediate efforts investigative work was not actively pursued for a time. Many conjectural explanations, however, were offered in the early days of transverse fissures, some remotely bearing upon the subject. It is believed these have been generally abandoned by their proponents.

Classified reports of rail fractures for a few years succeeding the Manchester accident did not specify transverse fissured rails as a distinct group. Some rails escape proper classification even at the present time. A report of the commission in 1923 on the prevalence of transverse fissures on 17 railroads showed the location by mile-posts of over 8 000 fissured rails. The number of known transverse fissures at the present time exceeds 22 000, representing several thousand heats of steel ⁽¹⁾.

Transverse fissures appear in rails of different chemical composition, with tendency greatest in the hardest steels. High-carbon steels have displayed them

in large numbers. They appeared in chrome-nickel steel rails prior to the Manchester accident. They are found in rails from all parts of the ingot. On some roads they predominate in rails from the upper part of the ingot; on other railroads chiefly from the upper and lower parts. Again, they have appeared in the D rails in greatest numbers up to the age of four years, after which the B rails equalled in numbers the D rails. They are found in rails of different weights per yard. They have not been reported in very light weight rails, undoubtedly due to mild track conditions. The heaviest rails now in use, up to 136 pounds weight per yard, are not immune from their formation.

The display of transverse fissures is not confined to any one section of the country. They are most prevalent, however, in territory where traffic is heaviest. The influence of density of traffic is clearly shown on double track road. Rails which carry the greatest tonnage display the most fissures. Low rails of curves commonly display more transverse fissures than high rails. In regard to the rails themselves, fissures predominate on the gauge side of the head. There is reason for believing that speeds of trains have an influence, high speeds accelerating their development.

The time required for their display varies from a few months to a term of years. The interval of time in the track from 5 to 15 years embraces the majority of the fractures. The extreme range is from a few months to 30 years. Bessemer rails chance to be among the oldest. Hard steels, density of traffic, and wheel loads are factors the influences of which are paramount in the development of transverse fissures.

The weight of the rail, or specifically the size of its head, within limits, does not exert a substantial influence in the relations of the internal strains set up therein. The volume of metal disturbed by the wheel loads is regarded a vital

⁽¹⁾ *Bulletin of the American Railway Engineering Association*, March 1927, states that 22 469 transverse fissured rails have been reported up to 31 January 1926, and that they are occurring at approximately 4 000 per year.

factor in relation to the development of transverse fissures. It is not altogether the intensity of the impinging pressures in a strict statement of the case, but the progressive change of intensity of pressure from center of effort to circumference that exerts a modifying effect on the physical properties of the steel. Following the laws which govern in cases of cubic compression it is the progressive difference in pressure on circumambient particles of the steel that affects their properties, rather than the total pressures on each. The dimensions of the heads of rails, however, do not bring into consideration this ultimate phase of the problem. As the matter stands the intensity of the impinging pressures between the tread of the wheel and the running surface of the rail and the volume of metal disturbed, the latter depending upon the magnitude of the wheel loads, constitute the factors which introduce internal strains that cause or tend to cause the formation of transverse fissures. This is a general statement of the case and one which attaches to the conditions of all rails.

No mystery surrounds the formation of a transverse fissure, nor has there been one at any time. The explanation is simple. There is an exterior strain of compression, an interior strain of tension. The metal is fractured by tension. Rupture is possible only by tension or shear.

Another question, however, was at once injected into this matter, a distinct one, having no relation whatsoever as to why the origin of the fracture was located in any definite place, interior or exterior. It had to do only with the matter of endurance, why one steel differed from another in its ability to resist track or other stresses. That question is now uppermost, and whether the margin in strength and endurance has not been reduced in some cases to a narrow margin, in others obliterated.

A perfectly legitimate question is raised in respect to endurance which all

would like to know about. By concurrence of opinion engineering practice has established standards of stresses to which important structural members may be exposed or not exceeded. The stresses in tensile members are restricted to certain values, in pounds per square inch of sectional area. Likewise compression members are restricted to certain unit stresses, modified in long columns according to ratio of slenderness. Coming nearer to railroad engineering, the manufacturers of ball and roller bearings establish definite limits to the loads on roller paths. It has not come to notice that any restrictions have been imposed, or even advocated, upon the loads which shall be concentrated on the head of a rail. However, this matter was referred to but not acted upon in an item of the American Railway Engineering Association in its program for 1924, which read : « The determination of the maximum permissible wheel loads imposed by the passage of wheels of various diameters. »

There is no real occasion to appear astonished or awe stricken over the thousands of rails which are displaying transverse fissures in the tracks. The development of interior fractures is entirely consistent with our knowledge of the strains which are set up in the interior of the heads of rails by action of wheel loads on their surfaces. The rails are obeying a physical law by which all members which sustain loads, carried upon wheels, are governed.

Descriptive remarks will follow upon influences to which rails are exposed in fabrication and in use. Special tests are necessary to illustrate the action of certain forces which affect rails relating to changes which occur within limits too narrow to admit of study in the rails themselves.

Cooling strains of fabrication.

Cooling strains are set up in all rails. They are set up in all cast, forged, and

rolled shapes, the magnitude of which depends upon the rate of cooling. The more rapid the rate of cooling, the more intense the internal strains, culminating in spontaneous rupture in cases of sudden quenching. Relief from cooling strains is attained by slow cooling from elevated temperatures. Mass and shape have an influence on the rate of cooling and, therefore, upon the magnitude and disposition of the acquired internal strains.

The cooling strains in rails have been measured on many occasions. This is done by establishing gauge lengths on certain elements along the length of the intact rail, then detach the strips on which they are located, and remeasuring their lengths after they have been detached. An initial state of compression is shown by expansion in length of the strip, tension by its contraction in length. The strains thus measured are converted to equivalent stresses by reference to the modulus of elasticity of the metal, taken in round numbers for steel at 30 000 000 pounds per square inch. On a gauged length of 10 inches each increment or decrement in length of a 1/10 000 of an inch therefore represents a stress of 300 pounds per square inch of compression or tension, respectively.

Figure 15 illustrates the places along the length of the rail where strains of compression or tension are found after normal conditions of cooling, also zones where shrinkage cracks occur. Cooling strains are greatest at the edges of the flanges, least in the metal of the head. Thin flanges acquire higher cooling strains than thick ones. The head cools more slowly, on account of its mass, and acquires strains of less magnitude. Rails of the heavier sections commonly show moderate cooling strains in the head.

Rails emerge from the last pass of the rail mill at different temperatures in different parts of their cross section. They are cambered to compensate for this difference in temperature between the head

and the base of the rail, taken as a whole. No compensation of this kind is possible for the difference in temperature between the flanges of the base and the thicker metal at the junction of the web and the base, nor for local strains at the fillets of the web. Neither can there be any mechanical adjustment for strains between the peripheral and the interior metal of the cross section at any part of the rail. So-called balanced sections have little to commend themselves in this respect.

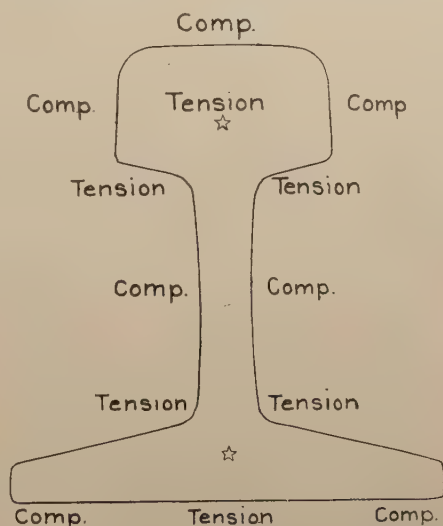


Fig. 15. — Locations of strains of compression and tension in rails of normal cooling. Stars indicate zones where shrinkage cracks occur.

A rail is certain to have strains, internal and external, lengthwise and crosswise, in its primitive state from the rail mill. As a whole the rail has a definite neutral axis from whence its section modulus is derived. It also has a number of neutral axes with reference to its cooling strains.

Placed within the outlines of the rail, as shown by figure 15, are stars indicating the location of zones where shrinkage cracks occur. At some period during the operation of cooling, internal

strains of tension are set up, which occasionally are of sufficient magnitude to cause interior cracks in the rail at these two zones. It has been found that these shrinkage cracks do not extend to the hot sawed ends of the rails. They cease at approximately the same distance from the hot sawed end as the distance in laterally from the periphery to the shattered zone. This evidence fixes the period of their formation subsequent to the hot sawing operation. The character of the cracks leads to the belief they form while the central core is at a fairly high temperature, when the interior metal has but little tensile strength but is in a plastic state.

Shrinkage cracks are very minute and may escape detection microscopically or macroscopically. They contain no foreign inclusions. They are more readily detected with the microscope on a medium polished surface than on a highly polished one. Decarburizing the metal brings the walls of the cracks prominently into view. Draw filing often shows the location of minute cracks, the fine chips from the file becoming polarized and arrested at the cracks. Pickling in hot acid enlarges the cracks by putting some of the metal into solution. The latter method of examination is a convenient one for their immediate detection but destroys essential evidence in their study.

Shrinkage cracks are oriented in different directions, in planes normal or oblique to the axis of the rail. They signify the relief, partial or complete, of the cooling strains of fabrication. They should not be confused with longitudinal streaks and seams of considerable length, which represent acicular slag inclusions. Slag or silicate globules in the ingot are drawn out into acicular streaks in the finished rail.

Shrinkage cracks are held by some as essential antecedent conditions for the inceptions of transverse fissures. In some cases they do furnish the locus; incipient fissures having been found

originating in shattered zones. Other transverse fissures have been located unassociated with shrinkage cracks, and still others in rails where search has revealed no shattered metal whatsoever.

This feature of shrinkage cracks, however, is deserving further observation and study. Cumulative data on the prevalence of shrinkage cracks in transverse fissured rails of different ages would assist in forming judgment on their influence, whether an accelerating or a retarding one, and whether they concentrate or diffuse the forces which tend toward the formation of transverse fissures. Shrinkage cracks represent the relief of shrinkage strains by reason of the rupture of the metal. As such they would seem retarders in the development of transverse fissures. Sharp, re-entrant angles in steel are known to be objectionable, nevertheless it has been shown that a certain augmentation in strength is given by adjacent parts in such cases. Stresses of the kind here referred to do not admit of accurate definition. Conclusions as to their effects must be reached by means of service records of the behavior of the rails in order to clarify these obscure points.

Shattered zones, similar to those of the head, are found in the metal at the junction of the web and the base. No example of a transverse fissure has been displayed in this part of the rail. Measured track stresses have shown higher tensile stresses in the base than those of the head, under beam action. Hence it follows that bending stresses do not appear controlling factors in the formation of transverse fissures. The lower surface of the base, resting on a tie-plate, is exposed to a limited amount of wear, and not infrequently experiences a hammering effect between rail and tie-plate. But conditions there are not comparable to the impulses directly received from the wheels on the top of the head. Fractures displayed in the head and the base are distinctly different and due to different causes.

**Normal and accelerated cooling,
also effects of gagging.**

Numerical values, stresses pounds per square inch, representing the cooling strains of fabrication are illustrated by figure 16 for a rail cooled normally in air. The stresses here given were present in a 127-pound medium manganese steel rail. The manganese content was 1.67, carbon 0.68. Compression stresses of moderate degree prevailed in the periphery of the head. Tensile stresses not measured in the central core of the head, required to balance the external stresses, were necessarily of moderate degree. Tensile stresses were displayed at each of the fillets of the web, the intermediate portion of the web being in a state of initial compression. Higher stresses of compression prevailed in the edges of the flanges than elsewhere.

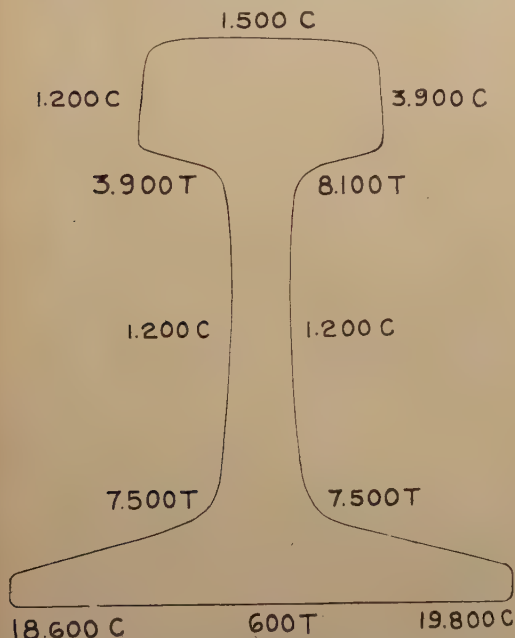


Fig. 16. — Stresses corresponding to the cooling strains of fabrication in a medium manganese steel rail, weight of rail, 127 pounds per yard. Manganese content, 1.67; carbon, 0.68.

These general relations between the cooling stresses of the head and flanges of the base are maintained in rails normally cooled on the hot bed. Attention has sometimes been called to the local cooling of the rail where it rests upon the skids of the hot bed. Strain gauge measurements on experimental sections cooled on an iron platform have not shown important modifications attaching to this feature.

An active period in the adjustments of internal strains takes place while the rail is cooling on the hot bed. The cambered rail at first is shortest along the base. The head cools, contracts, and straightens the rail. Different parts of the cross section of the rail differ in temperature, consequently pass over the recalescent periods at different times. A continual change takes place in the magnitude and relations of the internal strains, some parts being in a state of tension, other parts in a state of compression, with neutral axes intervening.

The cooling strains of fabrication may be lowered by retarded cooling or raised by accelerated cooling. Cooling mediums, air, oil and water, emulsions of oil and water and brine each have their peculiar influence. Of these mediums brine is the most energetic, air the least.

Figure 17 illustrates the stresses in a 100-pound rail of accelerated cooling. This rail was cooled by an air blast, directed upon the top of the head. It was cooled, from the finishing temperature of the rail mill, with an air blast of 10 pounds pressure of 4 minutes duration. The high values of the initial stresses will be noted, a maximum of 29 100 pounds compression, 11 700 pounds tension, making a total range of 40 800 pounds per square inch. To balance these peripheral stresses the internal stresses must have been correspondingly high. A favorable opportunity is presented to develop internal shrinkage cracks by accelerated cooling.

Figure 18 illustrates the stresses in a

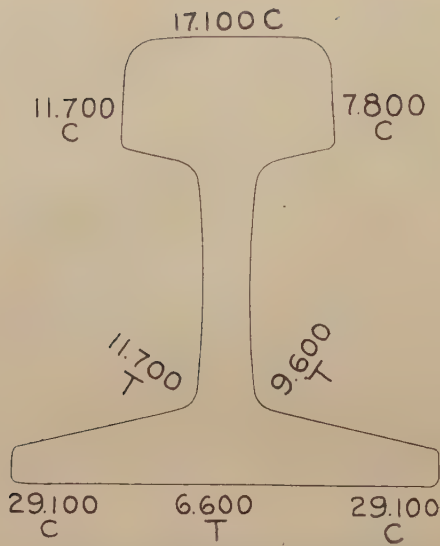


Fig. 17. — Initial stresses in a 100-pound rail, cooled by an air blast directed on the head; 10 pounds pressure of 4 minutes duration.

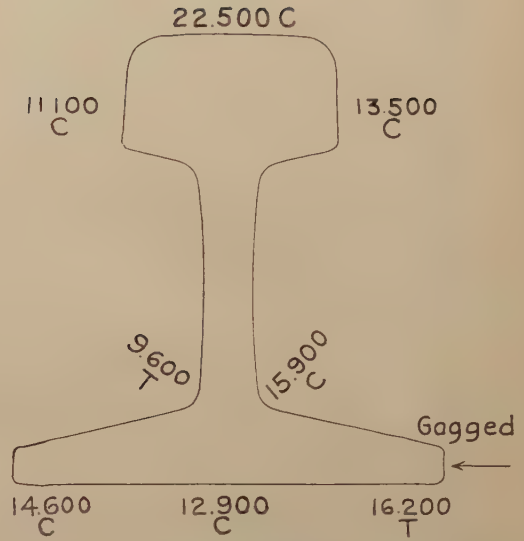


Fig. 18. — Initial stresses in a 100-pound rail reversed from compression to tension by the operation of gagging. Air-cooled rail same as figure 17.

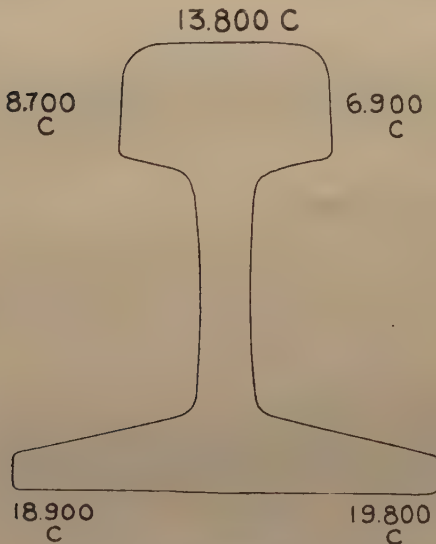


Fig. 19. — Initial stresses in a 100-pound rail cooled from a temperature of 1400° F., by an air blast directed on the head; 10 to 12 pounds pressure of 6 minutes duration.

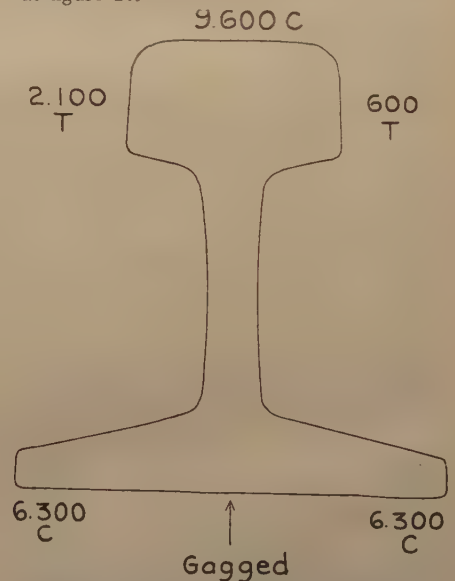


Fig. 20. — Initial stresses in a 100-pound rail after gagging on the base. Air cooled rail same as figure 19.

rail which was gagged on one flange. This was a 100-pound rail, air cooled in the same way as the rail last illustrated and described. It will be noted that internal stresses in the flange which received the gagging blow were reversed from the normal state of compression to that of tension. Also that a corresponding reversal of stresses occurred at the fillet of the web and the base on the side struck by the gag. Furthermore that the usual state of tension along the middle of the width of the base was changed to compression. An abrupt transition is shown by the stresses in the opposite fillets of the web and base; 15 900 pounds compression on one side against 9 600 pounds tension on the other. This made a range of stresses at the fillets of 25 500 pounds per square inch, while in the opposite flanges of the base there was a range of 30 800 pounds per square inch.

Figures 19 and 20 represent two 100-pound rails of accelerated rate of cooling, each cooled from 1 100° F. with an air blast of 10 to 12 pounds pressure, of 6 minutes duration. One rail was gagged on the base. The initial stresses of compression of the base were lowered in values two-thirds. The initial stresses in the sides of the head were reversed from compression to a state of tension. Reversal to a state of tension in the flanges would no doubt have been accomplished if the gagging had been carried further.

The internal strains set up in a beam bent beyond its elastic limit enumerated from the concave side to the convex side are strains of tension, compression, tension, and compression, respectively. To make these remarks clearer, a beam bent beyond its elastic limit springs back a certain amount when the load is removed, until a state of equilibrium of interior strains is established; whereupon the metal at the inside of the bend is put into tension; at the outside of the bend into compression; the reverse of the strains in the metal contiguous to the neutral axis; the metal immediately ad-

jacent to the neutral axis not having been overstrained.

This disposition of internal strains, together with the changes in the values of the elastic limits of tension and compression, respectively, which occur in overstrained metal, has a bearing on the initial state of a rail which has been gagged. Internal strains are always in a state of equilibrium, but easily dislocated after cold bending. Bending stresses in the track, which reverse those of the gag, readily cause permanent sets in the rail. The elastic limits of tension and compression, respectively, in hot worked steel are commonly equal, but overstraining in one direction impairs the value of the opposite elastic limit. The operation of gagging, which to be effective must overstrain the metal, therefore impairs the elastic limits.

This feature was illustrated in laboratory tests of a 100-pound rail. After overstraining in one direction permanent sets were developed by reversal of load at one-third the fiber stress at which sets of the same magnitude were displayed before overstraining. The same phenomenon has been illustrated in the alternate straining of steel bars by direct tension and compression. The total primitive elastic range in stress of 100 000 pounds per square inch, 50 000 pounds each of tension and compression, was not retained after once overstraining in either direction. The sum of the two elastic limits thereafter fell much below the original range of 100 000.

This characteristic feature has a bearing on the behavior of steel rails in two ways. Straightening by gagging leaves the rail in a condition susceptible of taking a permanent set in the reverse direction of the gagging, under stresses below its primitive resistance. The impinging pressures between wheel and rail tend to lower the elastic limits of the surface metal of the rail, thereby leading to greater depth of penetration of effect. Still another effect is noticed

from which the metal recovers. Overstraining has been found to temporarily lower the value of the modulus of elasticity. Still another illustration, the amount of power, mechanical work, required to rotate a shaft overloaded transversely is notably greater at the start than after a few rotations have been made. Confronted by these many features, it is hardly tenable to ascribe causes of fracture of steel rails in general to undefined mill conditions.

Successive annealing of detached strips from a rail.

Figure 21 illustrates the initial stresses

in a 100-pound rail, air cooled from the finishing temperature at the rail mill, with air blast of 6 pounds pressure of four minutes duration, after which the rail was gagged on the flange designated by the letter *e*. The flange which directly received the gagging blow was left in a state of tension, the opposite flange in a state of compression.

The detached strips on which the stresses were measured were subsequently annealed. The strips were successively shortened in length, as shown by the table which follows. Measurements were made on gauged lengths of 10 inches each.

GAUGED LENGTH.	Annealing temperatures.				Final equivalent stresses.
	1 450° F.	1 450° F.	1 600° F.	1 800° F.	
<i>a</i>	— 0.0115	— 0.0159	— 0.0265	0.0405	121 500
<i>b</i>	— 0.0091	— 0.0140	— 0.0250	— 0.0299	89 700
<i>c</i>	— 0.0146	— 0.0167	— 0.0286	— 0.0344	103 200
<i>e</i>	— 0.0082	— 0.0116	— 0.0194	— 0.0289	86 700
<i>g</i>	— 0.0042	— 0.0063	— 0.0158	— 0.0263	78 900

All strips were shortened as indicated by the minus signs in this tabular exhibit. No fixed relation appeared between the values of the initial stresses in the intact rail and the amounts which the detached strips were subsequently shortened. The stresses in one flange were reversed by the operation of gagging, but this circumstance did not prevent its following the same course as its companion and the other strips. A forging drawn down from a bloom was annealed. Measurements were made on different sides. The shortening was greatest parallel to the direction in which the metal had been forged.

These experiments indicate changes in the density of the steel, suggestive of many interesting lines of inquiry. At a very early date it was found that hardened steel bars would contract in

length upon exposure to a moderate rise in temperature, a few hundred degrees Fahrenheit. Two phenomena were simultaneously displayed; dilatation of the steel by reason of rise in temperature, accompanied simultaneously by an opposing contractile movement.

The figures entered in the last column of the preceding table, under the caption « Final equivalent stresses », indicate values corresponding to the maximum contraction of each strip; stresses which would be required to shorten the strips those several amounts if the shortening was done by compressive forces. Conversion to equivalent stresses gives a better opportunity to grasp the significance of these changes in dimensions, expressed in fractions of an inch, than statements of the strains taken alone.

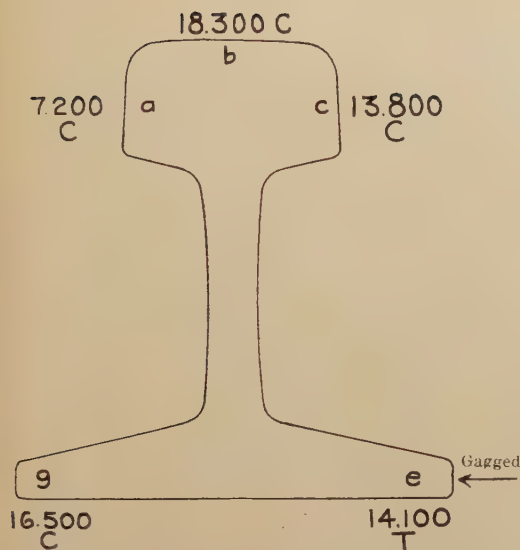


Fig. 21. — Initial stresses in a 100-pound rail air cooled gagged on a flange. Strip from head and base annealed.

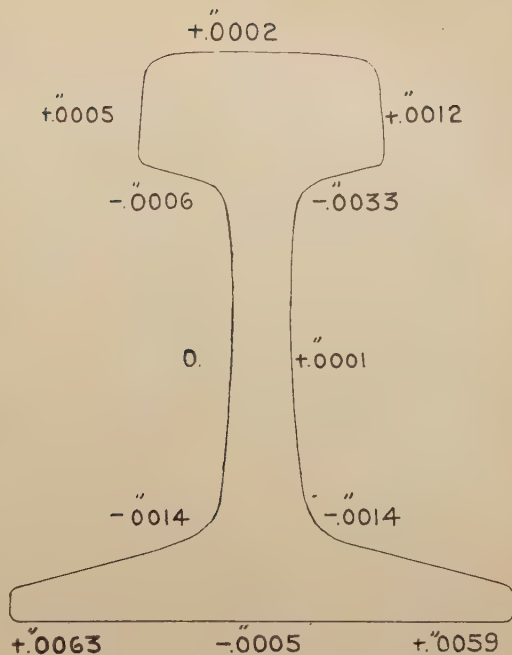


Fig. 22. — Measured strains in strips detached from medium manganese steel rail, 127 pounds per yard. Normally cooled.

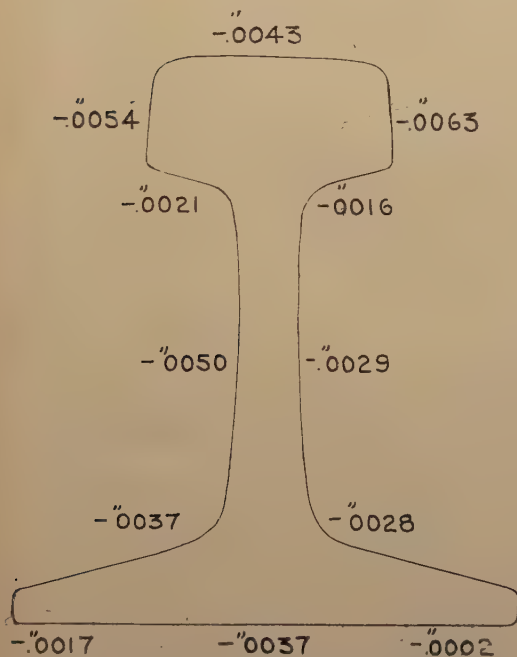


Fig. 23. — Changes in lengths of strips detached from medium manganese steel rail, figure 22, annealed.

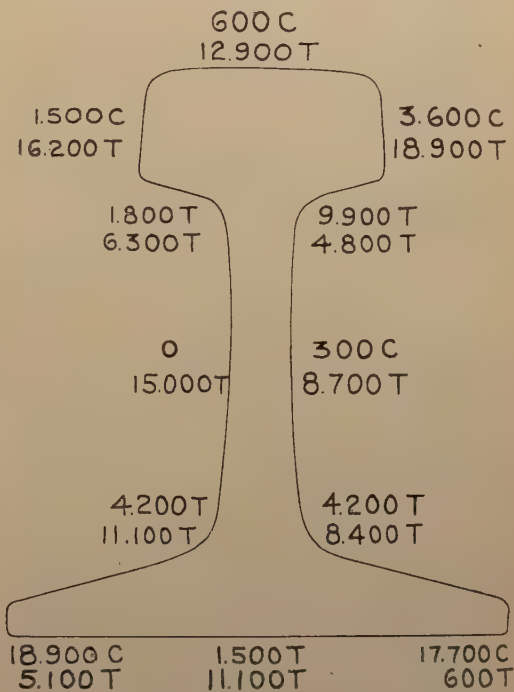


Fig. 24. — Stresses corresponding to the strains shown by figures 22 and 23.

Medium manganese steel rail : cooling strains and annealing of strips.

A group of three figures 22, 23, and 24, present results obtained with a medium manganese steel rail of 127 pounds weight per yard, the manganese content being 1.67, carbon 0.68. Figure 22 shows the measured cooling strains on 12 gauged lengths displayed when strips from the intact rail were removed. The strains ranged from 0.0033 to 0.0063 inch, representing stresses of 9 900 pounds per square inch tension to 18 900 pounds compression.

The detached strips were twice annealed in lime, on each occasion at 1 450° F., resulting in the contraction in length of each of the several strips. The total contractions of the detached strips resulting from the two annealings are shown by figure 23. The corresponding values of these strains, expressed in pounds per square inch, are shown by figure 24.

Again it was found that the contractibility of the strips did not bear a fixed relation to the cooling strains acquired by the rail during fabrication. Strips which in the intact rail were under the opposite strains, of compression or tension respectively, when annealed contracted amounts apparently irrespective of their primitive condition. With different tendencies in these individual strips it would seem that some migratory movements might take place in the annealing of an intact rail.

The cooling strains in the flanges of this medium manganese steel rail were higher than usually found in rails of its weight and thickness of flange. Minimum changes during the processes of annealing took place in the lengths of the flange strips. These variations in decrements of length doubtless possess some peculiar significance in the physics of the metal but of what they consist is not known.

Results deduced from the results shown by figures 22 and 23 are given on

figure 24. The upper set of values refer to the stresses which existed in the rail, as normally cooled in air. The lower sets of values represent stresses corresponding to the measured decrements of length of the detached strips after they had been annealed. A large number of figures placed on a single diagram are apt to be bewildering; but at this time, for comparison of results, it becomes necessary to present them in juxtaposition.

Flange strip successively shortened, then successively lengthened by heating and cooling.

Tests were made with a strip detached from a flange of a 100-pound rail, illustrating first a successive shortening in length after which it was successively lengthened, each by heat treatment. The strip was taken from a 100-pound rail

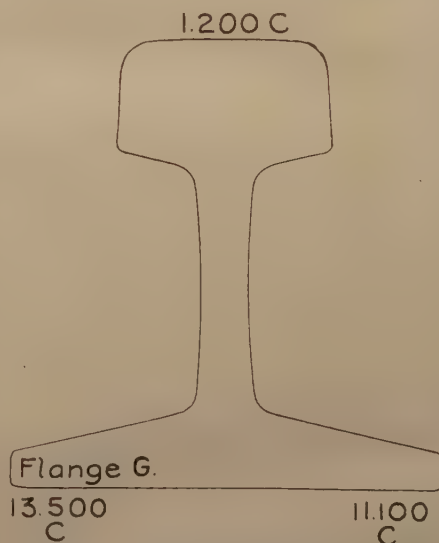


Fig. 25. — Strips from flange G, 100-pound rail normally cooled.

Heated strip shortened by slow cooling; lengthened by rapid cooling.

cooled normally in the air. Figure 25 illustrates the internal cooling stresses of

fabrication, measured on three elements — at the top of the head and on each flange of the base. The strip detached from flange *g* was successively shorten-

ed by heating followed by slow cooling, after which it was successively lengthened by heating followed by rapid cooling.

The results of the test were as follows:

Treatment of strip from edge of flange « g ».

[Strip detached from intact rail + 0.0045 inch, 13 500 compression.]

TREATMENT.	Successive strains.	Equivalent stresses.
Heated to 1 450° F. and slowly cooled	— 0.0100	30 000
— again to 1 450° F. and slowly cooled	-- 0.0120	36 000
— to 1 600° F. and slowly cooled	— 0.0198	59 400
— to 1 800° F. — — — — —	— 0 0303	90 900
Heated in electric furnace and quenched in water from 485° F.	+ 0.0005	1 500
— — — — — 580° F.	+ 0.0010	3 000
— — — — — 670° F.	+ 0.0016	4 800
— — — — — 840° F.	+ 0.0030	9 000
— — — — — again from 840° F.	+ 0.0033	9 900
— — — — — from 1 400° F.	+ 0.0041	12 300
— — — — — 1 300° F.	+ 0.0225	67 500
— over open fire and quenched from 1 400° F.	+ 0.0510	153 000

Two different phenomena are illustrated in these tests of shortening or lengthening the strip of rail at will by heating and varying the rate of cooling. A physical change resulted from heating and slow cooling, a mechanical result was reached by heating and rapid cooling.

Phenomena common to different steels.

Other features will be referred to which have a relation to the conditions of exposure of rails in the track, and influences of composition of the steel. Steels of different composition have shown different coefficients of expansion, traceable to the different amounts of carbon present. From this it would appear that carbides of iron have different properties than ferrite. Low-carbon steels and puddled irons have a

higher coefficient of expansion than high-carbon steels and cast irons. The influence of the microconstituents is thus believed to be shown. There are similar differences in the specific gravities of the low and high carbon steels. Low-carbon steels are the heavier.

It was early shown that cold rolling diminished the density of steels, cold-rolled shafting being lighter than hot rolled. Similarly, steel under stress is lighter than when in repose, as indicated by Poisson's ratio. Specific gravity determinations made upon the truncated ogival-shaped ends of tensile specimens have shown lower values than presented in the original hot-rolled bars.

The lowering of the value of the modulus of elasticity at higher temperatures; increase in strength, when cold, imparted to the steel by overstraining at moderately high temperatures; ability to

permanently elongate different amounts, differing several hundred per cent, according to the method employed; or the entire destruction of this ability; difference in rate of conductivity of heat over the transmission of strains; all of these features are encountered in some degree in the experience of rails in process of fabrication or in use in the track. It is comparatively easy to effect the rupture of steel. It is a difficult matter to regulate stresses, attain a maximum degree of efficiency, and still retain a safe margin in strength. The features which have been described are those which steel rails experience, many of them being of common occurrence. Reference will now be made to influences and results directly relating to the track.

Internal stresses in rails acquired in the track.

Figure 26 illustrates the stresses which were present in a 90-pound rail, after service in the track. Those of the head were modified by reason of a bond wire having been brazed to the outside, upper edge. The structural state was disturbed by the effects of the torch, indicated by the shaded portion of the sketch. A cross section of the rail was smooth polished, and the zone of affected metal brought into view by etching with ammonium persulphate.

Heating with the torch, for brazing, overcompressed the metal for the time being which reversed the internal strains to a state of tension when the rail cooled. This brazing which was done near the end of the rail, on the outside of the head was the safest place such heating could be applied without menace to the integrity of the metal. The use of the torch on the web or the base of the rail would endanger its safety, leading to its rupture. The formation of cracks has been witnessed on the tread of a chilled iron wheel. Experimentally a small area of the tread was heated with an oxyacetylene torch raising the temperature of

the metal to a dull red heat. During the period of cooling a small network of cracks was formed on the surface of the tread, representing the relief of internal strains of tension.

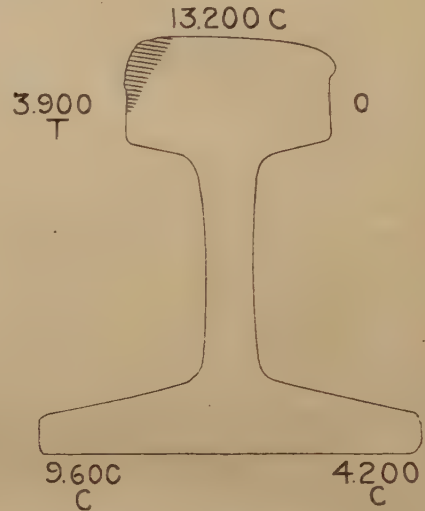


Fig. 26. -- Internal stresses in a 90-pound rail modified by brazing a bond wire on side of head.

Figure 27 illustrates the internal stresses of a 100-pound rail from the tracks of the Interborough Rapid Transit Railroad of New York City. Its composition was C. 0.81, Mn. 0.86, P. 0.029, S. 0.042, Si. 0.10. The total tonnage carried by this rail was 300 839 315 tons. The wheel loads were fairly light, understood to have been in the vicinity of 15 000 pounds on the motor end of the car. Notwithstanding the moderate wheel loads, rails in the tracks of this company have not been immune from the display of transverse fissures.

Figure 28 represents a low rail of a 3° 40' 10" curve; its weight was 130 pounds per yard. The average composition of the rails to which this belonged was C. 0.682, Mn. 0.64, P. 0.021, S. 0.058, Si. 0.077, Ni. 0.59, Cr. 0.24. The internal strains were measured after the rail had

been in the track 16 months. The middle element along the top of the head had acquired strains equivalent to 21 000 pounds per square inch compression. These are cold rolling strains which come from the impinging pressures of

the wheels. It is unlikely that the cooling strains of fabrication exert a material influence on the strains later acquired from the impinging action of the wheels; that is, in rails cooled normally on the hot bed.

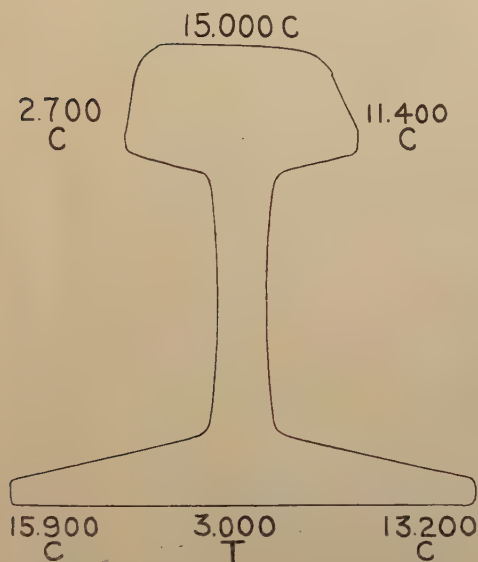


Fig. 27. — Internal stresses in a 100-pound rail from the tracks of the Interborough Rapid Transit Railroad, New York City.

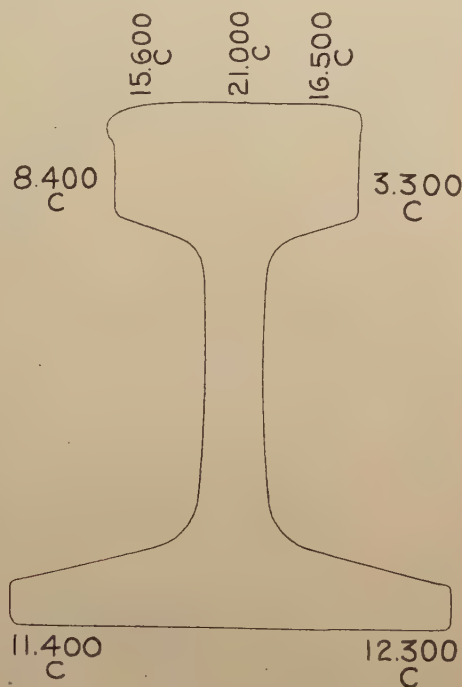


Fig. 28. — Internal stresses in a 130-pound rail, low rail of a 3° 40' 10" curve, after 16 months in service.

The stresses here mentioned are above the average which have been observed, but do not represent maximum values in steel rails. The measured strains, in any case, are not the maximum ones to which the rail head is subjected. They represent the permanent effects of the wheel loads, after the loads have been removed, and not the strains endured by the rail while it is being loaded.

There is a discrepancy in values between the measured strains of tension along those elements in which transverse fissures are located and the strains

which experimental research show necessary to effect rupture under repeated stresses. The difference is in part made up by the increased strains to which the rails are exposed when in a loaded state. Experimental results however, represent observations made upon the average behavior of masses of steel, and do not illustrate what happens between elementary parts of the metal, where fractures originate. But fractures which occur under the influence of one force, and one force only, must be attributed to the action of that force. This syllo-

gism aptly applies to the formation of transverse fissures.

Figure 29 illustrates the appearance, in cross section, of an early, puddled,

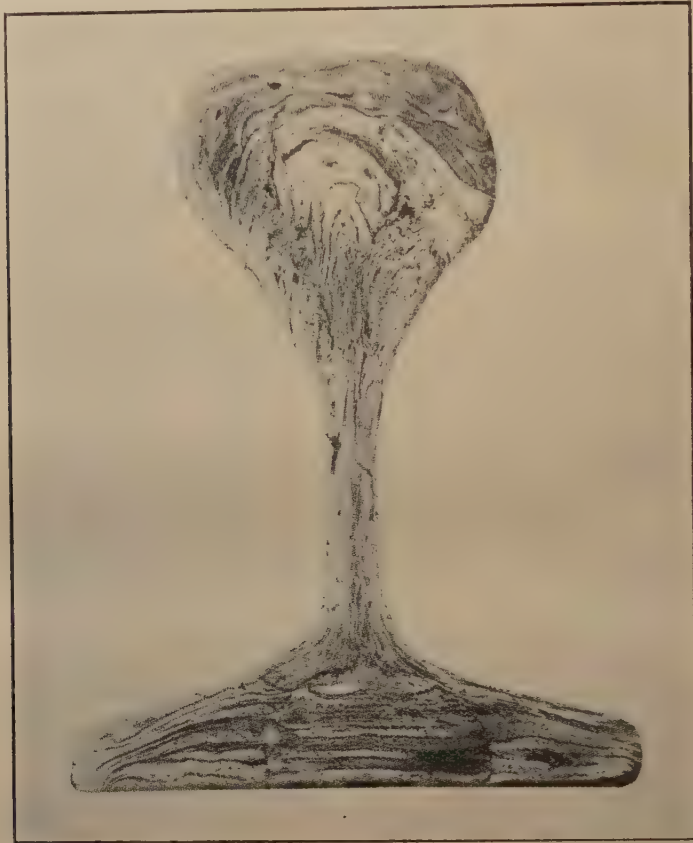


Fig. 29. — Cross section of an early wrought-iron rail, etched with tincture of iodine.
Internal stress in top of head 24 920 pounds per square inch compression.

iron rail, of about 40 pounds weight per yard, after etching with tincture of iodine. Internal strains in the top of the head were equivalent to 24 920 pounds per square inch compression. The detached strip on which these strains were measured assumed a pronounced convex shape, with the running surface uppermost, indicating the internal strains were of variable degree in magnitude, greatest adjacent to the running surface.

The lower wheel loads, in the days of wrought-iron rails, had their influence on the introduction of internal strains on that weaker metal as they now do on the stronger steel rails. No transverse fissures were ever reported in iron rails, but split heads were of common occurrence. The wrought-iron rails yielded by lateral flow of the metal of the head. The laminated structure of the metal was an obstacle to the formation of fissures

at right angles to the grain of the iron. Iron is strong lengthwise the grain, weak in crosswise direction. The dissimilarity in behavior of iron and steel has a resemblance to the difference between that of wood and glass.

Ability to retain internal strains essential in rails

The ability to acquire and retain internal strains is the very property which gives steel the power to endure wheel loads, without which railroads, as we know them, could not exist. The particles of the metal react upon each other. They may be strained up to a certain degree before internal rupture ensues. Mild steels, under uniformly distributed loads, will display the phenomenon of continuous flow under stresses far below the impinging pressures between wheel and rail in current railway practice. Mild and medium grades of steels have this period of continuous flow without advance of stress; hard steels rupture in shear before this period is reached.

Hardened steel balls and cylindrical rolls possess a degree of rigidity difficult to obtain in their roller paths. Nothing approaching their rigidity is experienced in wheels and rails of railway practice. Although the hardest steel rails retain their shapes, and under outward appearance appear to be unaffected by wheel pressures, nevertheless they are overstrained, acquire internal strains, which tend to cause and do culminate in transverse fissures. Additional examples might be presented of measured strains in new rails and in those after a period of service in the track. They would merely confirm what has already been stated.

When internal strains from wheel loads are introduced they disturb the relations of preexisting strains. Likewise the removal of strips from one part of the rail disturbs the remaining portion of the cross section, loss of metal by abrasion doing the same. A special test

illustrated the reactions in overstrained bar, when portions of its cross section were successively cut away. A rectangular bar bent cold into the shape of a horseshoe has internal strains of tension and compression in each of two zones. They are disposed in the manner which has previously been alluded to; tension on the inside of the bend, compression on the outside. It is indifferent whether metal is planed off the concave or the convex side of the bend, the arms will separate in consequence thereof. After sufficient metal has been planed off the movement of the arms reverse and then move toward each other. Due to increased leverage, the release of strains is magnified and made easily noticeable at the ends of the arms.

Internal strains in rails may be reversed, tension changed to compression or vice versa within narrow limits. In thin metal sheets they may be reversed within minute limits. Since rupture results from the minute separation of adjacent particles, it is believed that a careful consideration of the phenomena relating to internal strains is not only desirable but necessary in the study of the causes of the rupture of steel rails.

Compound type of transverse fissures.

The terminology transverse fissure was applied specifically to a type of fracture witnessed in a steel rail in which a state of longitudinal strain led to its interior formation. It is frequently observed that fractures which originate from a definite cause are diverted from their primitive courses, detaching small fragments or resulting in the complete rupture of the rail. Crescent-shaped breaks in the bases of rails are examples of this kind. They originate at longitudinal seams or laps, commonly at the middle of the width of the base, and are diverted to the edges of the flange. Similar fractures occur in the heads of rails, especially in hard steels. A horizontal split head, with origin at

an interior streak or seams, is diverted from its course detaching a flattened crescent-shape fragment leaving the rest of the rail intact. In other cases the plane of rupture is deflected downward and developed transversely to the axis of the rail. A compound transverse fissure is thus formed. Surface indications of its presence may be and generally are absent. Such an interior fracture presents the same danger in the track as a simple transverse fissure.

Figures 30 and 31 represent this type of transverse fissures, with origin at a minute longitudinal streak or slag seam. A small silvery oval formed about the acicular seam, at one end of which the fracture was deflected downward. Figure 30 shows this branch, fan-shaped, with nucleus at the end of the acicular seam. The silvery oval is shown by figure 31, the extension of the fracture at one end branching upward. In this fracture interest attaches to the presence of the minute acicular seam, which led to the display of this compound transverse fissure.

Figures 32 and 33 illustrate another compound transverse fissure, at an early stage of its growth. Its nucleus was at a longitudinal acicular seam, the origin of a horizontal split head fracture. The saw scarfs shown by figure 32 were made for the purpose of detaching the top of the rail and revealing the surfaces of the horizontal split head fracture. In this example the transverse fissure, which branched from the horizontal split head, took an upward course.

Figures 34 and 35, obverse and reverse of the same fragment, illustrate still another compound transverse fissure. The origin of this fissure was at a horizontal split head from which it deflected in a downward direction. The transverse fissure separated the larger part of the cross section of the head and extended into the web. This was a 100-pound rail, ingot letter G. The fracture was completed in the testing machine.

The reverse view of the rail shows two nearly horizontal, but slightly inclined, cracks in the upper part of the head. These were apparently shearing fractures, the top of the head being cold rolled and separated from the metal below without presence of a longitudinal seam. These shearing cracks were obscure, the shorter one hardly perceptible. They were made prominent for photographing by draw filing, allowing the polarizing chips to gather about the cracks.

Figure 36 illustrates a transverse fissure which, in its development, was arrested by the presence of a vertical split head fracture. Its growth, however, continued by extending over and beyond the upper edge of the vertical fracture. This rail furnishes an example of reverse action to preceding illustrations of compound fractures where horizontal split heads branched, upward or downward, into transverse fissures. In the present example the nucleus of the transverse fissure was on the gauge side of the head remote from the vertical crack. The transverse fissure was stopped at the vertical crack. This rare combination of fractures prompts the query: If a large seam or crack possesses the ability to stop a transverse fissure would it be expected that a small seam would possess the ability to start one? The matter resolves itself into the question of orientation, this example tending to eliminate from consideration the presence of longitudinal seams as essential precursors in the formation of transverse fissures. If they are not vital, anxiety would center solely upon those shrinkage cracks which are oriented in planes substantially normal to the axis of the rail.

Mechanical extension of split head fracture.

Figure 38 represents the vertical crack in the head of the rail on the end opposite the transverse fissure which is shown by figure 36. After its further

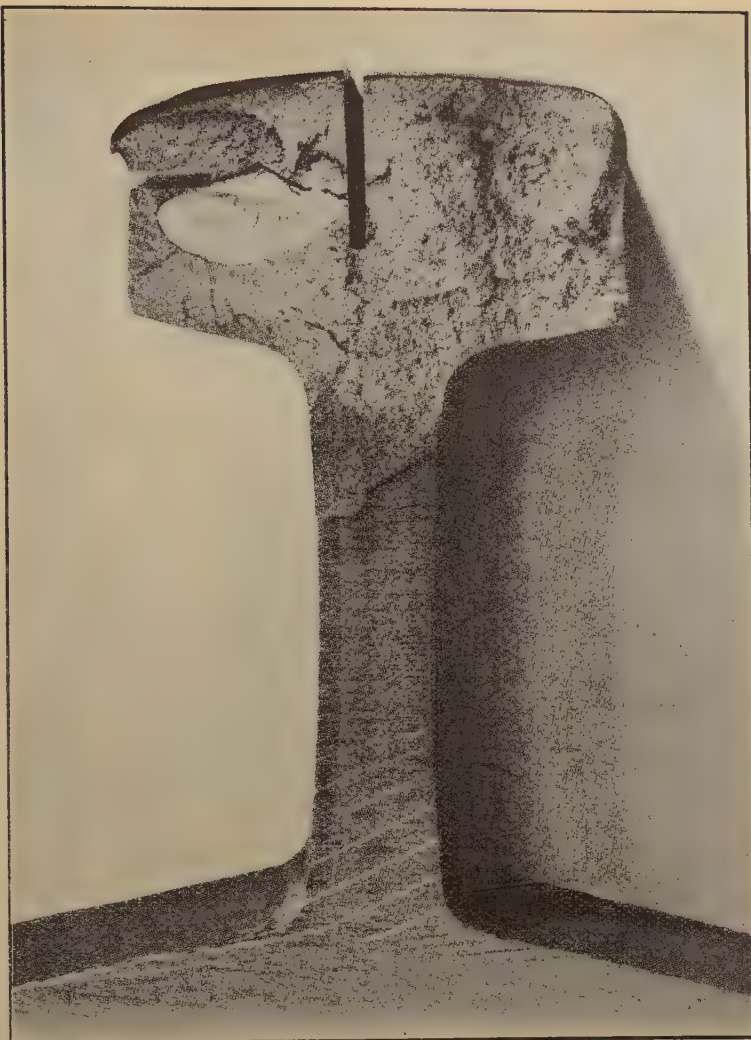


Fig. 30.

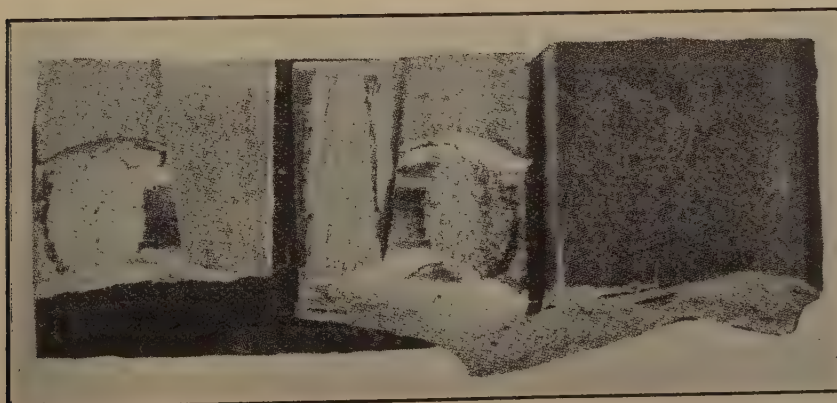


Fig. 31.

Figs. 30 and 31. — Compound transverse fissure originating at a small longitudinal seam.
 Vertical development shown by figure 30,
 horizontal oval fracture containing longitudinal seam shown by figure 31.

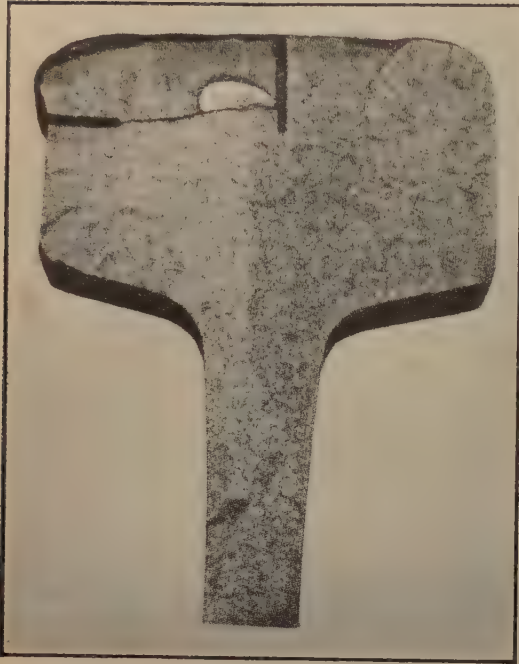


Fig. 32.

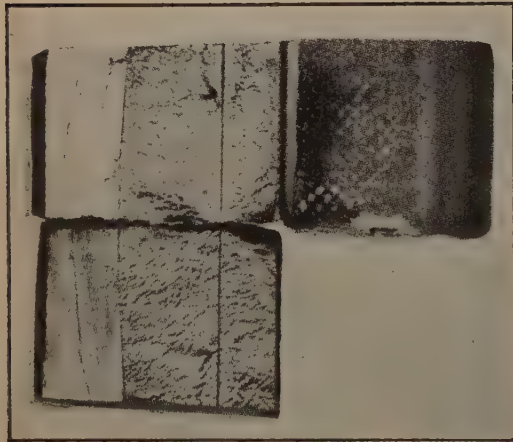


Fig. 33.

Figs. 32 and 33. — Compound transverse fissure. Horizontal split head branching upward into a transverse fissure. Origin of split head at longitudinal seam.

development the split head fracture is shown by figures 37 and 39.

The fracture of this rail illustrates the effects of two forces, a longitudinal force which developed the transverse fissure and a crosswise force which developed the split head. Each for a time were probably developed independently of the other. Cold-rolling effects are felt in two directions, setting up strains of compression both lengthwise and crosswise the rail. It is unusual, however, to find associated fractures of these two types.

Perhaps these fractures were not of simultaneous origin, but when the transverse fissure had reached the middle of the head its progress was unquestionably arrested by the vertical crack. The upper part of the transverse fissure then crept over its top.

The split-head fracture extended in depth to a point abreast the fillet under the head. The upper part only is clearly shown by the cut. This feature will be noted, that in the formation of the split head fracture the metal of the head was separated two thirds its depth without indications of its presence being presented on the running surface. The usual dark streak along the middle of the running surface, so much relied upon as visible evidence, is an indication of a split head which comes late in its development. When a dark streak becomes visible to the observer, the final stage of fracture is about reached. The narrowness of this split head crack is again shown by figure 38.

After photographing, the split head fracture was extended by mechanical means analogous to the action of wheel pressures. The top of the head was peened with a hand hammer, setting up strains of compression which eventually were sufficient to cause an upward extension of the crack. The peening was continued, along the middle of the length of this short section of rail, until the vertical crack reached the top of the head at each end of the specimen. Figures 37 and 39 show the results.

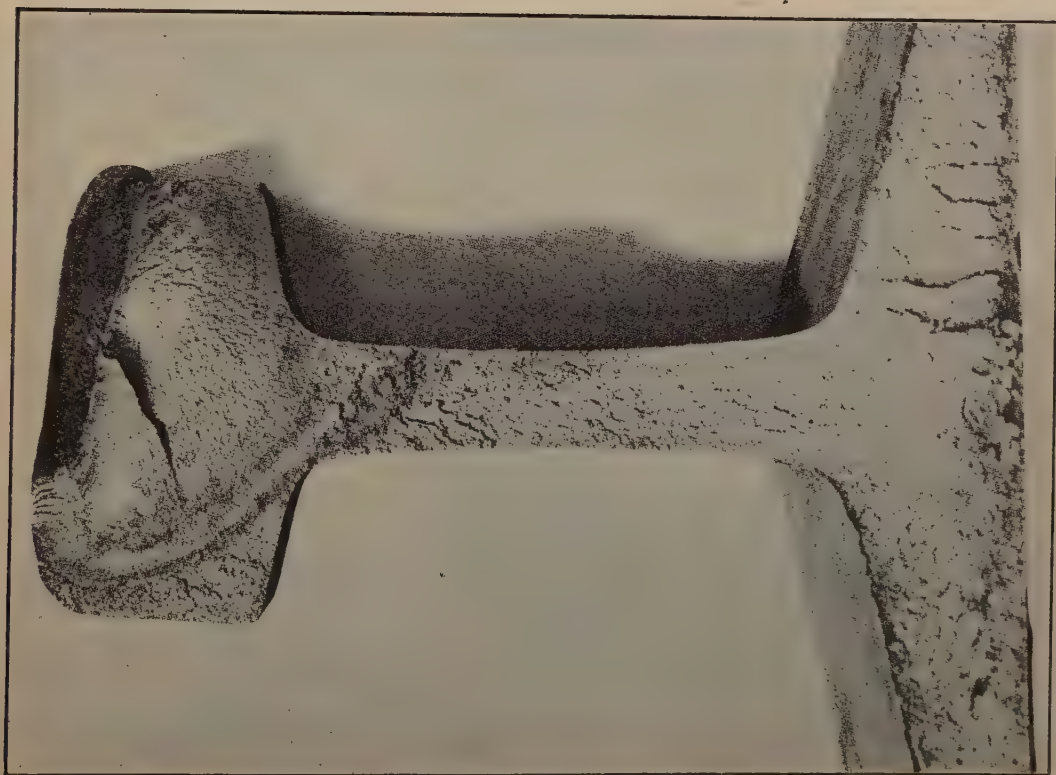


Fig. 34. — Compound transverse fissure in a 100-pound rail, originating at a horizontal split head.

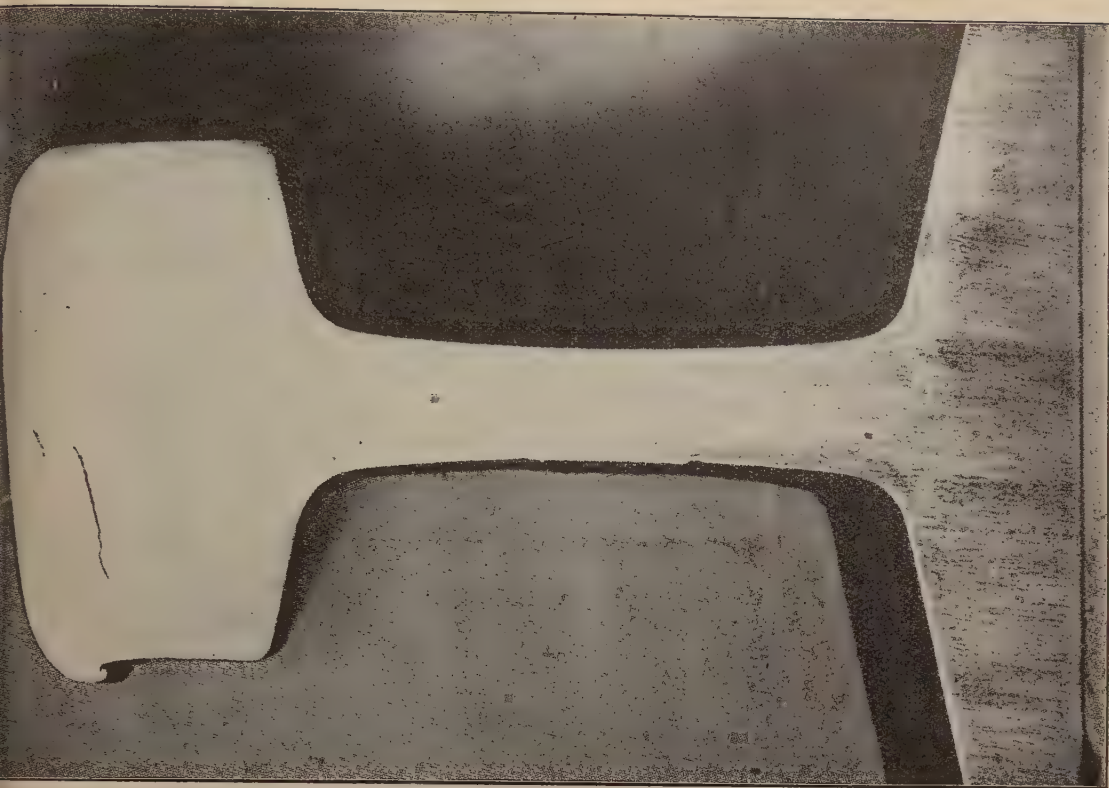


Fig. 35.

Fig. 34, transverse fissure branching downward from split head. Fig. 35, two horizontal split-head cracks, the longer of which led to the formation of the transverse fissure.

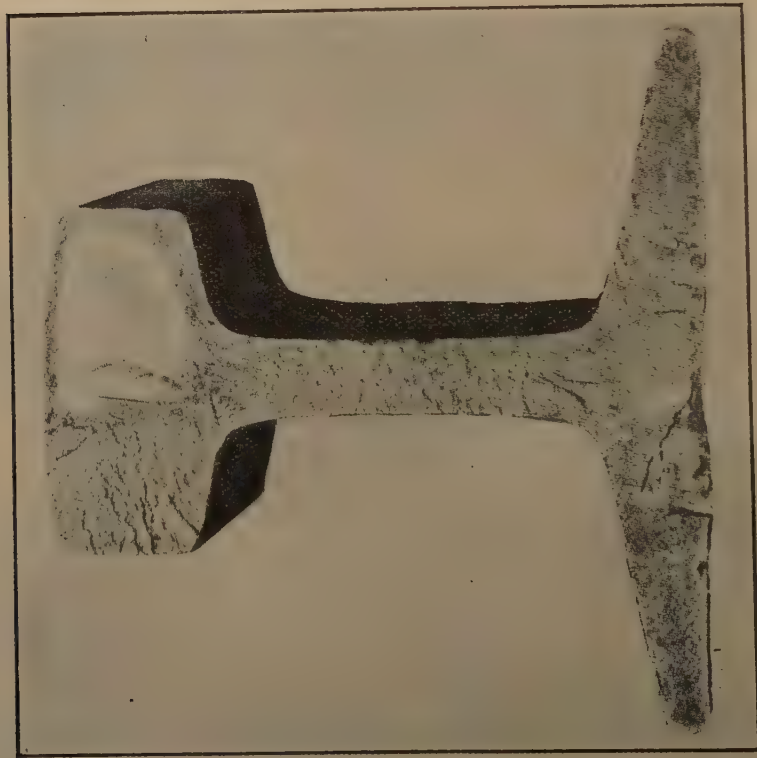


Fig. 36. — Transverse fissure in a 85-pound rail arrested at a split head fracture.

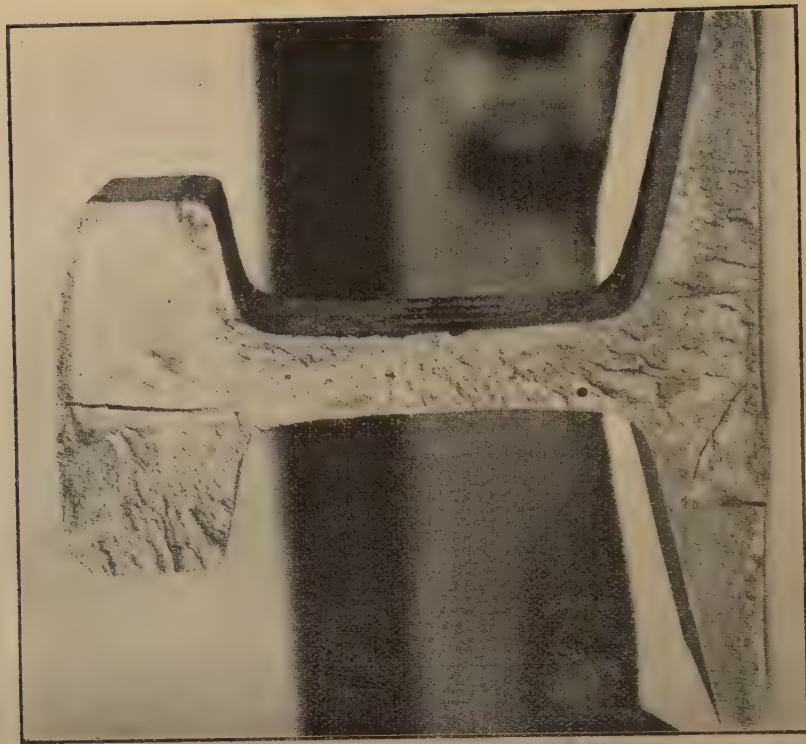


Fig. 37. — Split head fracture of figure 36 extended across transverse fissure by peening to running surface of head.

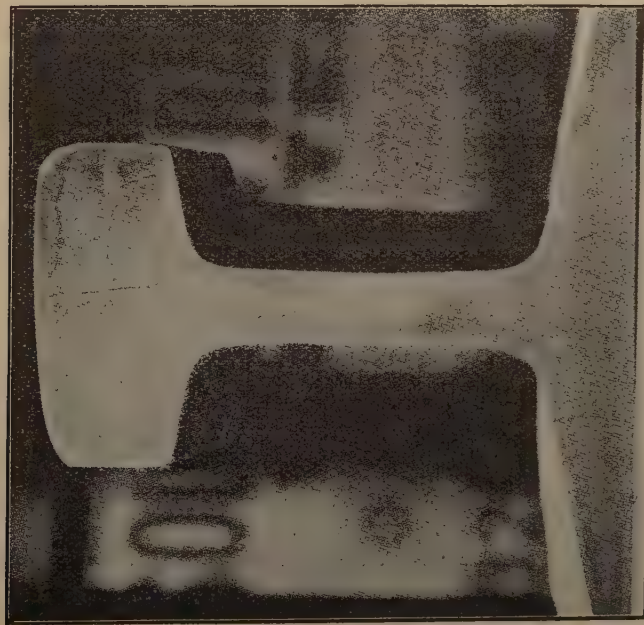


Fig. 38. — Split head fracture in an 85-pound rail.
Opposite end of short fragment figures 36 and 37.

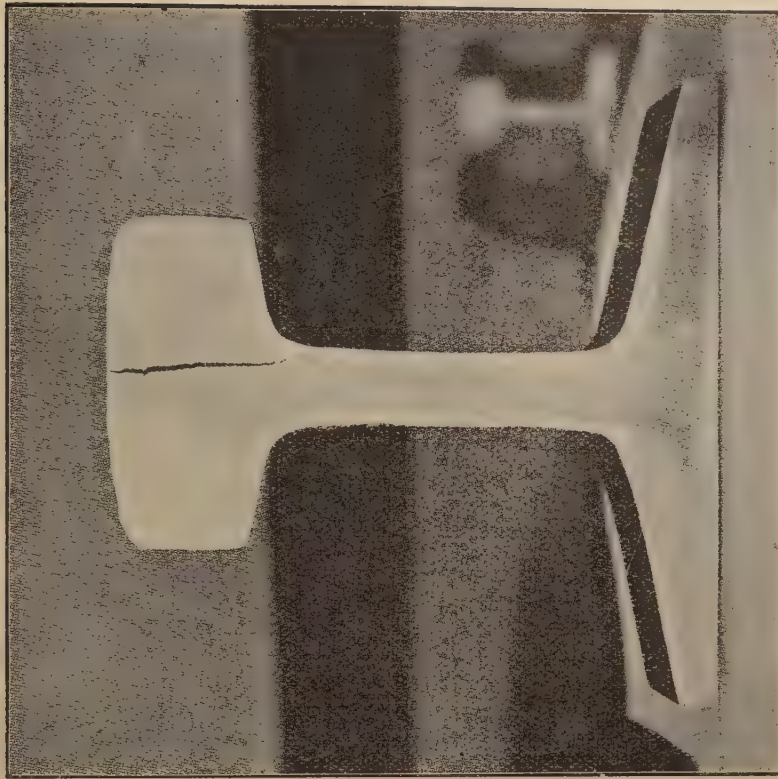


Fig. 39 — Split head fracture of figure 38 extended by peening to running surface of head.

The mechanically extended crack passed through the overlapping surface of the transverse fissure. In the absence of longitudinal resistance the influence of the peening was felt only in a cross-wise direction. There is no reason for believing the extension of an incipient transverse fissure could not be accomplished in the same manner. In fact it has been done with a small fragment of the head of a rail.

One of the reasons why transverse fissures commonly develop into oval-shaped surfaces is the requirement that some portion of the cross section of the metal of the rail be in a state of compression to react upon and strain by tension the periphery of the transverse fissure. The metal immediately below the running surface of the rail is virtually cold swaged, the grains of the steel flattened and, as well known, steel under such treatment will display greater ductility than possible in a tensile test where the total elongation has a relation to its tensile strength. Malleability is the term which best expresses the ability of steel to flow under swaging pressures.

External evidence of either a split head or a transverse fissure is presented only upon a close approach to final rupture. A sag in the head means that longitudinal rupture along the fillet has nearly taken place, extending the fracture excepting a thin layer of metal below the running surface. At that stage there is similarity in action between the shearing of a fin from the side of the head and detaching a major portion of the metal of the head. The practical difference, however, is great, in respect to the element of danger.

In general, the actual separation of the surface metal of a split head rail first occurs in the fillet under the head; and the first visible surface separation of a transverse fissure is commonly on the side of the head or in the fillet.

Figure 40 illustrates the development of a transverse fissure in a 100-pound open-hearth vanadium steel rail. A large

part of the cross section of the head had been fractured. The transverse fissure reached the surface on the gauge side of the head, substantially its entire depth. The fissure extended nearly across the width of the head but without reaching the running surface. The feature of malleability preserved the metal from rupture at the immediate top of the head. This rail displayed a transverse fissure after one year, 20 days' service.

The presentation of a transverse fissure which covers so large a portion of the cross section of the head gives emphasis to the query concerning its rate of growth, whether uniform, accelerated, or retarded. Under the present state of knowledge a definite answer can not be given. A prognostication would depend upon complete knowledge of the forces which contribute to cause the fissure together with a consideration of the resistance of the rail at different stages in its growth.

Bending stresses not principal factors in the display of transverse fissures

The properties of carbon steel are such that bending stresses can not be held accountable for the display of transverse fissures, except in a secondary degree. As a beam the strength of the rail would rapidly diminish with the growth of a fissure. The growth of two transverse fissures in close proximity would be practically incompatible with beam action. When, however, a sufficient degree of weakness has taken place by reason of the extension of the transverse fissure the fracture of the balance of the rail suddenly occurs in the track, in the manner which it would fracture under a bending stress in the testing machine. Since the rail sustained the bending stresses of the track while this weakening effect advanced it does not follow necessarily that final rupture occurred solely under the effects of bending loads.

With so small an area of unruptured metal above the periphery of the trans-

verse fissure, as displayed by the rail illustrated by figure 40, the completion of rupture does not admit of being attributed to the influence of the area of intact metal above the fissure. Some recent results, which will be referred to later in this report, suggest the influence of longitudinal vibrations as a possible factor in the final fracture of transverse fissured rails.

It has long been suspected that steel rails, not unlike metal located in other places, would respond to the influence of vibratory waves. Vertical waves are clearly apparent in the track, occurring under all speeds of trains. Under transverse vibrations the outside fibers of the rails would be most affected, but these vibrations do not seem of greatest importance to fractures which develop from within the periphery. In respect to longitudinal vibrations the matter presents a different aspect. Heretofore in reports upon transverse fissures no reference has been made to vibratory strains, for the reason there was no evidence available associating such strains with the fractures of rails. Evidence of such a nature has come to hand which will be incorporated herein.

Head checked rails.

Figure 41 illustrates a type of fracture in a 100-pound rail to which the name head check has been applied. It originates at the surface of the head at or near the upper corner at the gauge side. It develops in a transverse plane. Originating in a locality where internal strains of compression are acquired some special reason for its inception must be present. It is apparently a type of wheel burning, in which strains of tension have been introduced.

A series of photomicrographs each 100 diameters magnification illustrate the appearance of the steel near the top surface of the rail, Nos. 42 to 47 at places indicated by letters placed on cut No. 41. Figure 42 represents a longitudinal sec-

tion, at the running surface of the rail, near the upper corner, gauge side. There was hardened and cracked surface metal, with a zone of hardened steel next below in which outlines of the grain structure remained. Figure 43 shows the depth of the hardened zone with the normal structure of the steel beyond. Nos. 42 and 43 slightly overlap each other.

Figures 44 and 45 show the flattened grains of the steel near the upper outside corner of the head. Below a shallow layer of hardened metal the grains were flattened, with an outward flow. These two are transverse sections. Figure 46 shows the distortion of the grain on a transverse section near the middle of the top of the head. Figure 47, also a transverse section, shows the normal grain structure of the steel below the affected zones.

In respect to internal strains, relations have not been established between the zones of metal of normal shape and those of flattened grains. It has been found possible, in the lathe, to turn off roughing chips from a steel axle of such depth of cut and feed that internal strains of tension resulted in the metal below the chips removed.

A thin layer of affected metal next the running surface was shown in early tests of steel rails. This layer of affected metal detracted from the bending properties of the rail, leading to brittleness of fracture when loaded to extremity. Annealing restored the toughness of the rail. This behavior demonstrated the fact that the cold-rolling action of the wheels destroyed the toughness of the metal prior to actual rupture. In the physics of steel it is a matter of interest to know that destruction of toughness, the ability to flow and take permanent sets, marks a stage in the approach to rupture prior to the actual separation of elementary parts.

This phenomenon appears to be witnessed in high manganese steel rails,



Fig. 40. — Transverse fissure in 100-pound O. H. vanadium steel rail.
Transverse fissure reached surface at side of head, but not running surface.

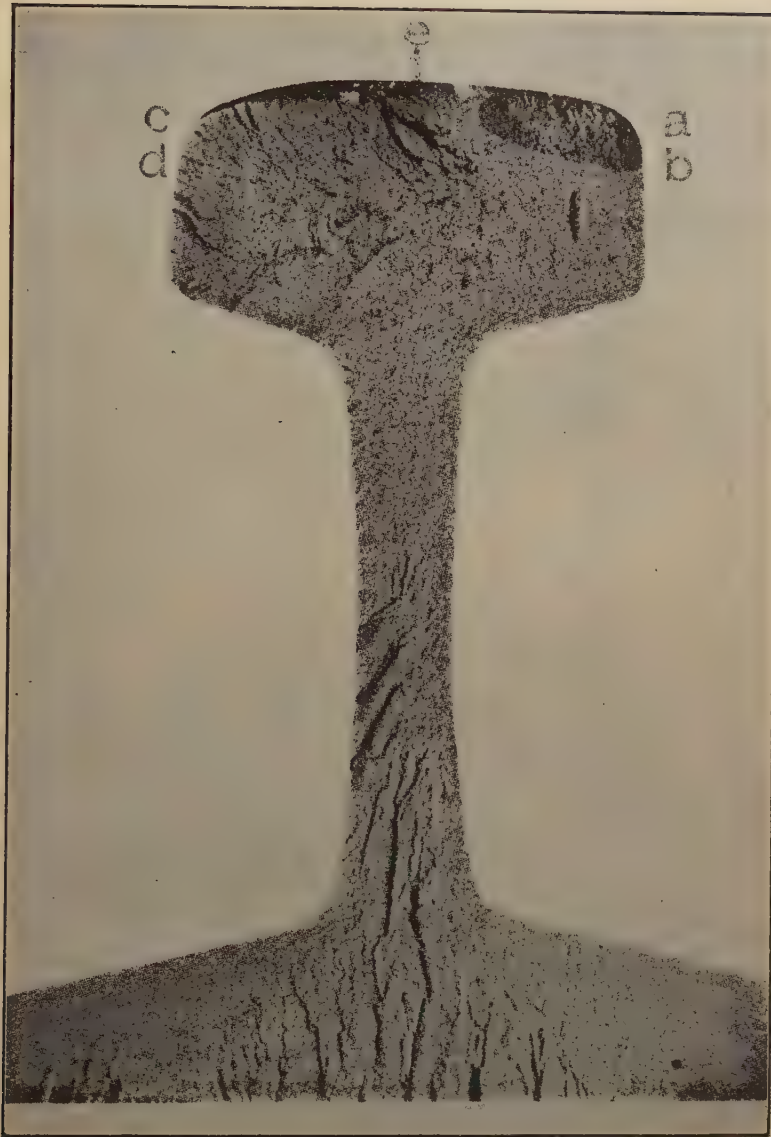


Fig. 41. — Head checked rail. Weight, 100 pounds per yard.
Microstructure shown by figures 42, 43, 44, 45, 46 and 47 for *a*, *b*, *c*, *d*, *e* and *f* respectively.

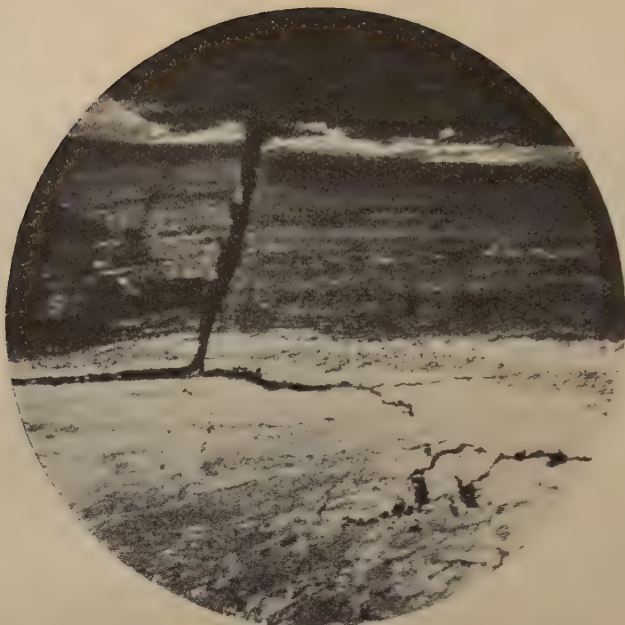


Fig. 42. — Microstructure at *a* (fig. 41).
 Hardened and cracked surface metal and hardened metal next below with outlines remaining
 of grain structure.
 Longitudinal section. Magnification 100 diameters.



Fig. 43. — Microstructure next below *a* (fig. 42).
 Hardened zone with normal structure below. Sharp line of demarkation.
 Longitudinal section. Magnification 100 diameters.

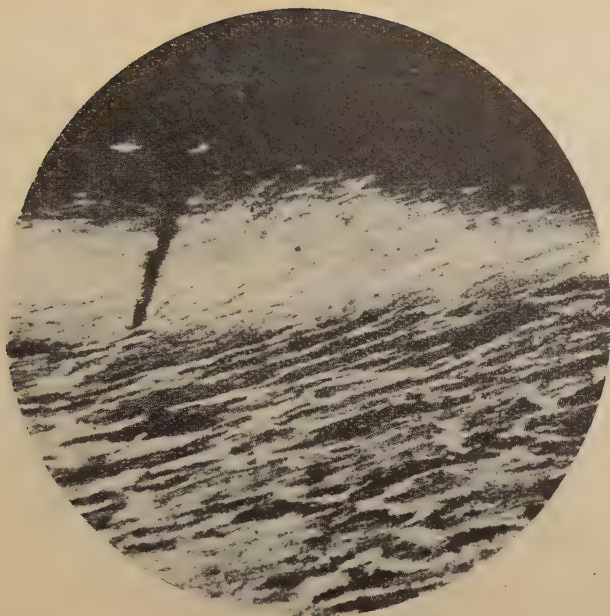


Fig. 44. — Microstructure at *c* (fig. 41), at running surface.
Hardened skin and flattening of the grains showing outward flow.
Transverse section. Magnification 100 diameters.



Fig. 45. — Microstructure below *b* (fig. 43),
near outside corner of the head, showing flattening of the grain, with outward flow.
Transverse section. Magnification 100 diameters.

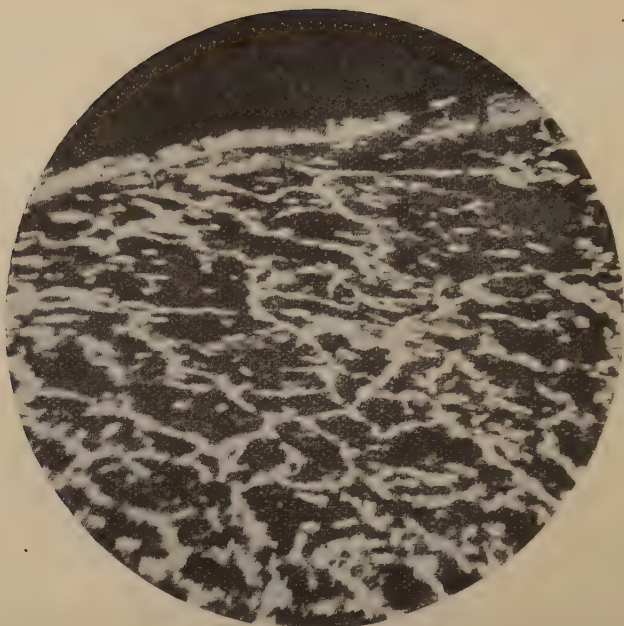


Fig. 46. — Microstructure near top of head, middle of width.
Slight hardening of the surface metal and shallow zone of flattened grain
Transverse section. Magnification 100 diameters.

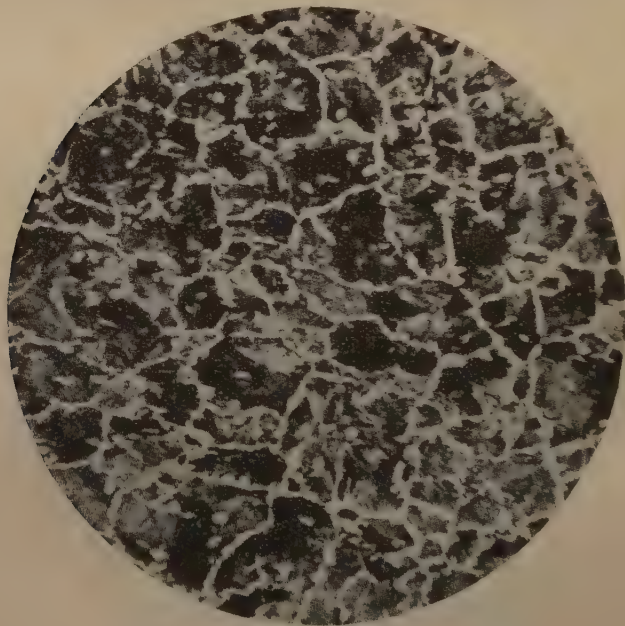


Fig. 47. — Normal structure of the steel.
Vicinity of upper part of head. Transverse section. Magnification 100 diameters.

leading to progressive fractures beginning at the running surface of the rail and extending downward through the head and into the web.

Figure 48 illustrates the gashes which were formed in the head of a high manganese steel rail in a bending test, with the head on the tension side. Fractures of this kind are not displayed by carbon-steel rails. The toughness of this remarkable material was destroyed by the cold rolling of the wheels at the immediate running surface. The toughness of the steel below the affected zone was retained and the extensions of these gashes restricted. In this feature the behavior of high manganese steel is unique. It possesses elements of safety against sudden rupture witnessed in no other steel.

Favorable reports have been announced concerning the resistance of rails of medium manganese content against the formation of transverse fissures, manganese of 1.25 to 1.75 %. Investigation of the properties of this grade of steel have shown it not unlike carbon steels, so far as laboratory tests indicate.

Transverse fissure in medium manganese steel rail.

Figure 49 illustrates the appearance of a transverse fissure displayed by a rail of medium manganese content. This was a Bessemer steel rail, 100 pounds weight per yard, which had been in service 13 years. Chemical analysis made of the metal from the top of the head gave the following results: C. 0.61, Mn. 1.23, P. 0.059, S. 0.153, Si. 0.142.

The transverse fissure was located 9 ft. 8 in. from the receiving end. The middle part of the length, 11 ft. 4 in., was broken into 56 pieces. The leaving end remained intact.

The circumstances of this being a Bessemer rail does not present an unusual feature. In a compilation of transverse fissured rails 698 Bessemer steel rails came to notice.

Wheel burnt rails.

Wheel-burnt rails are of common occurrence, every yard furnishing examples. They are specially prevalent wherever trains stop and start. The cause of their occurrence is the skidding of the wheels; their rotation being either faster or slower than the movement of the train, it is immaterial which. Some examples are pronounced by reason of the severity of their appearance, exhibiting deeply serrated and roughened surfaces of the heads of the rails while others hardly display any of these familiar manifestations. Wheel burning also appears in situations where it would not ordinarily be expected.

The frictional resistance encountered in the slipping of the wheels raises the temperature of the surface metal of the rail practically instantaneously. Frictional resistance is doubtless the most expeditious method of raising the temperature of steel to an incandescent heat. When heated suddenly and of short duration only a superficial layer of the metal is directly affected. By conductivity the metal next below quenches the intensely heated surface metal. In steels having the chemical composition of rails this sudden abstraction of heat effects thermal hardness of the metal. Similar effects are witnessed at the ends of cold-sawed rails.

In the microscopic examination of wheel-burnt rails, layers of hardened steel are found superimposed on metal of normal structure. Examples have also been witnessed in which the immediate surface metal had evidently been reheated and annealed. Those examples displayed an upper layer of annealed metal resting upon a hardened layer, which in turn rested upon metal of normal structural state. Different results will be reached according to the rate of heating, the degree of temperature reached, its duration, and the rate of cooling.

The usual appearance of a wheel-burnt rail requires no illustration. However,

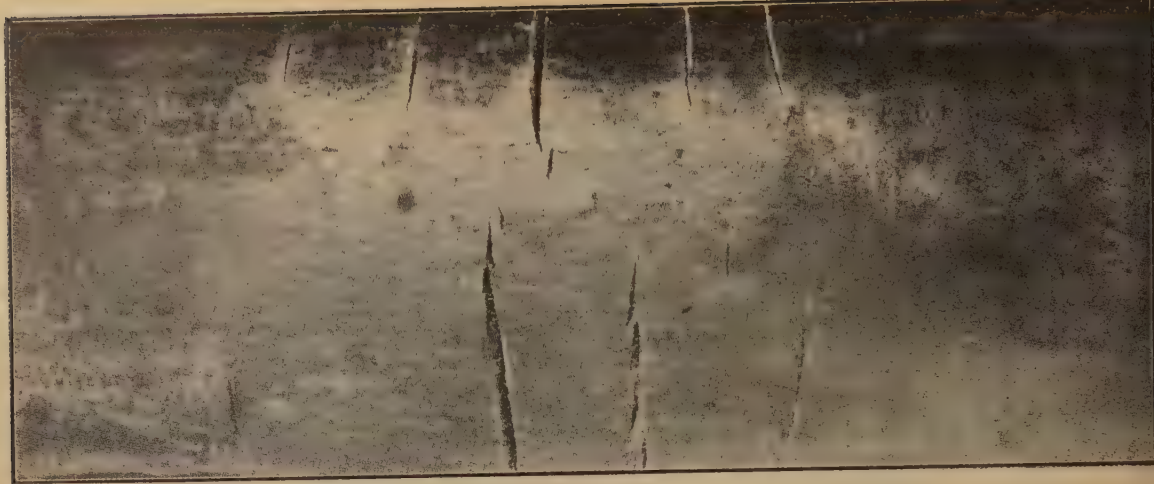


Fig. 48. — Manganese steel rail, 100 pounds weight per yard. Cracks in running surface developed in a bending test of the rail. Elastic limit approximately 54 000 pounds per square inch.



Fig. 49. — Transverse fissure displayed by a medium manganese steel rail. Bessemer steel. In service 13 years.

a better conception of the disturbed metal may be obtained by pickling in hot acid. Pickling may even reveal the presence of wheel-burnt metal not apparent when the rail was in the track. Flange-worn rails have exhibited such evidence. Rails have shown a series of thermal cracks, on the corner of the head, gauge side, of such regularity of spacing they resembled the graduations on a foot rule. Such thermal cracks have been witnessed on the low rails of a 3° curve.

In skidding, the wheels should not remain long in one spot to effect the hardening of the surface metal. Prolonged heating, due to the slipping of wheels without their advance, raises the general temperature of the entire head, with results entirely different from those which follow sudden heating and cooling. A very complex state of internal strain is set up by prolonged heating, depending upon conditions which fluctuate so widely that no accurate prediction can be made of what the final results will be.

An example of prolonged heating was presented in the wheel burning of some 90-pound rails, which were located in a tunnel. The wheels skidded for a time before it was realized the engine was not in motion. The tops of the heads of the rails were hollowed to a depth of 0.3 inch under the wheels. The entire heads and a portion of webs were heated red hot.

The internal strains in one of the rails were measured. At a stage in the examination of the rail the internal strains taken along one element of the head represented a stress of 16 200 pounds per square inch tension; while at another stage the stress along the same element represented 14 100 pounds per square inch compression. Planing away a portion of the cross section of the rail reversed the internal strains along the measured element.

Notwithstanding the structural injury ordinarily caused by wheel burning the injured zones are reinforced and held

together so efficiently, by virtue of the physical properties of the steel, that the rails are enabled to endure this severe treatment and remain intact and serviceable, at least in many cases. Rails which have fractured from this cause, which is also called snow burning in some sections of the country since such occurrences take place while ploughing out snowdrifts, have exhibited great local disturbance of the metal before they succumbed to these destructive influences.

Bolt-hole fractures.

Whenever steel is exposed to alternate stresses and of sufficient intensity the ability to permanently elongate under tensile stress is destroyed. Conditions at the walls of bolt holes in rails are such that loss of ductility is there experienced. The drilling of bolt holes, adopted many years ago to escape the objections to punching, does not eliminate the danger of rupture under service conditions.

Rails display brittleness of fracture at bolt holes. Fractures originate at their walls without appreciable enlargement of their diameters. This happens while the metal at adjacent bolt holes may still retain its ability to be drifted into much larger holes without rupture. The brittleness displayed is attributed, in part at least, to hammer action between the webs of the rails and the shanks of the track bolts. Clearance originally provided for is lost by the creeping of the rails. Bolts are frequently bent and the walls of the bolt holes are upset.

Some fractures take longitudinal courses across the horizontal diameters of the bolt holes; others form on oblique lines at angles 45° with the longitudinal axis of the rail. The display of oblique lines of rupture is taken to indicate that shearing stresses play a part in the formation of bolt-hole fractures.

The presence of this type of fracture is obscured in its early stages by the splice bars. Not until a fracture has ex-

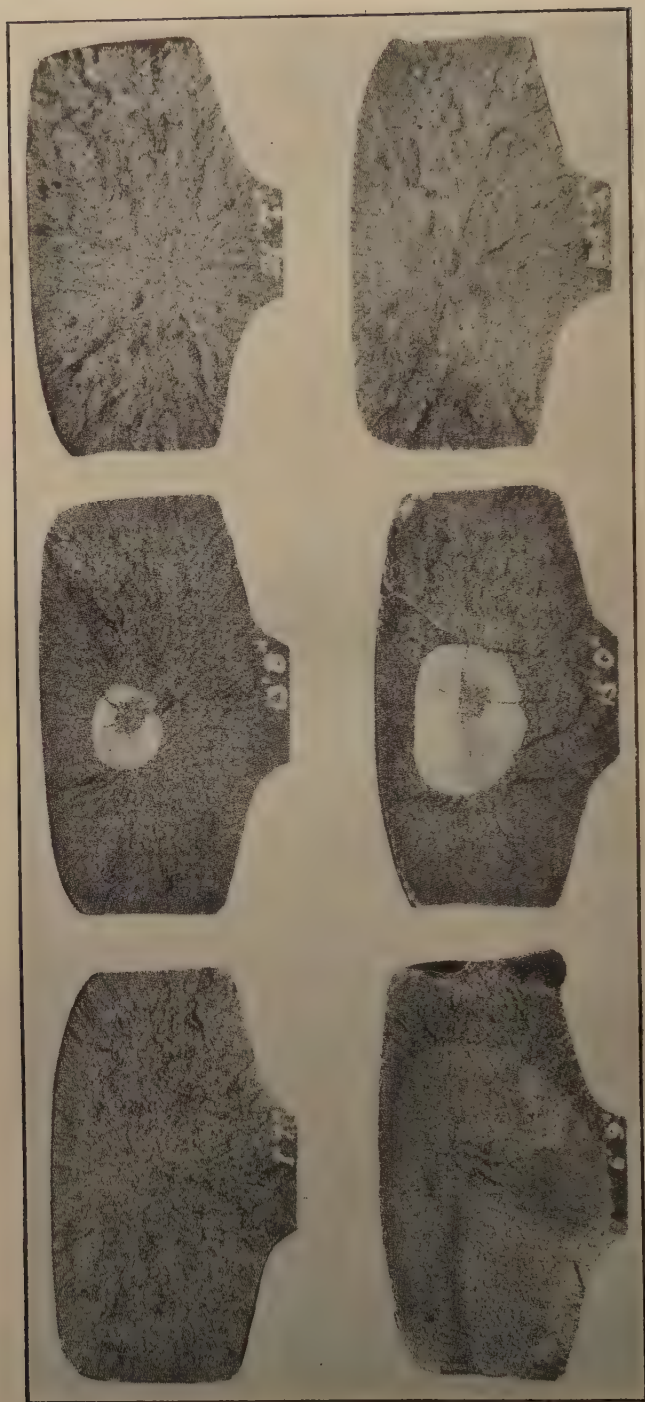


Fig. 50. — Stalling effects and transverse fissures in different stages of development in a 90-pound rail.
Fifteen fractured surfaces.



Fig. 51. — Starring effects and transverse fissures in different stages of development in a 90-pound rail. Fifteen fractured surfaces.



Fig. 52. — Starring effects and transverse fissures in different stages of development in a 90-pound rail. Fifteen fractured surfaces.

tended beyond their ends does it commonly admit of detection. In some cases a horizontal line of rupture bifurcates and completely detaches a short piece of the rail or separates a piece of the head from the web and base.

Artificial transverse fissures.

Transverse fissures have been produced experimentally in new rails. Their positions in the head of the rail was under control. They were developed centrally when the rail was loaded in upright position, or located in the right or left side of the head when the rail was canted to the right or to the left.

Artificial transverse fissures were made by means of gagging blows applied successively at short intervals along the head, then reversing the rail and repeating the blows along the base. The tests were made on half-rail lengths. Referred to full-rail lengths, the number of blows required to break the rails and disclose the transverse fissures ranged from 50 000 to 250 000. Each gagging blow was more severe than used in the ordinary straightening of a rail. These tests showed there is little need of anxiety concerning the effect of a score or less of gagging blows in the usual straightening in the gagging press, as affecting the integrity of the metal. Gagging blows in ordinary practice are delivered only once or twice in a place, and seldom in reversed direction.

In producing artificial transverse fissures it was necessary to gag the rails successively at short intervals along their lengths, reproducing as nearly as possible track conditions of continuous rolling by the wheels. Gagging in the same plane alternately on the head and the base resulted in regular beam fractures; that is, in fractures having their origins in the outside fibers of the rails.

Artificial transverse fissures were of interior origin, identical with those developed in the track. They displayed surfaces resembling the nuclei of track

transverse fissures, without the silvery burnished effect believed to be caused by the opposite surfaces being hammered together and closing the minute gap between them when the wheels are directly above them.

Different weights of rails and different heats of steel were represented in these artificial transverse fissures.

Transverse fissures in several places in the same rail.

Certain rails contain only one transverse fissure when they are removed from the track for the display of this type of fracture. In others several fissures exist in different stages of development. Among those which have been examined many have been found to contain more than one fissure. The transverse fissure displayed in the track is commonly a pronounced one in respect to size but not always the largest in the rail.

Figures 50, 51 and 52 illustrate the fractured surfaces of a rail which was broken, after removal from the track, in 15 places. At 11 places transverse fissures were in the process of development. Starring effect, so called, characterized four of the fractured surfaces.

In this group the fracture which was made at the distance of 28 ft. 1 in. from the leaving end of the rail displayed a minute silvery crescent. This manifestation identifies the fracture as an incipient transverse fissure. The nuclei of transverse fissures present characteristics shown in tensile fractures and likewise those of shrinkage cracks. The identity of an incipient transverse fissure becomes certain only when evidence is presented of its progressive formation; that is, when a silvery luster is shown on a portion of the fractured surface.

When a rail is broken under the drop with the head in tension a starring effect of interior location is commonly shown. This does not mean necessarily that the locus of a transverse fissure has been

displayed. It identifies the point where the metal first separated. Before rupture occurred the metal at that place, some distance from the neutral axis of the rail, may have elongated several per cent. The difference in behavior will be kept in mind between the measurable elongation of the metal in a rail fractured by a bending test and the absence of measurable elongation in the case of a transverse fissure. Erroneous interpretations of what has been witnessed

would account for the early announcements made upon the presence of embryonic transverse fissures in new rails.

Figure 53 is a line drawing showing the locations and diameters of 50 transverse fissures which were found in the same rail. One transverse fissure was displayed in the track, one in handling, and 48 others in its subsequent test under the drop. Some of the short fragments, the subjects of later studies, displayed additional fissures.

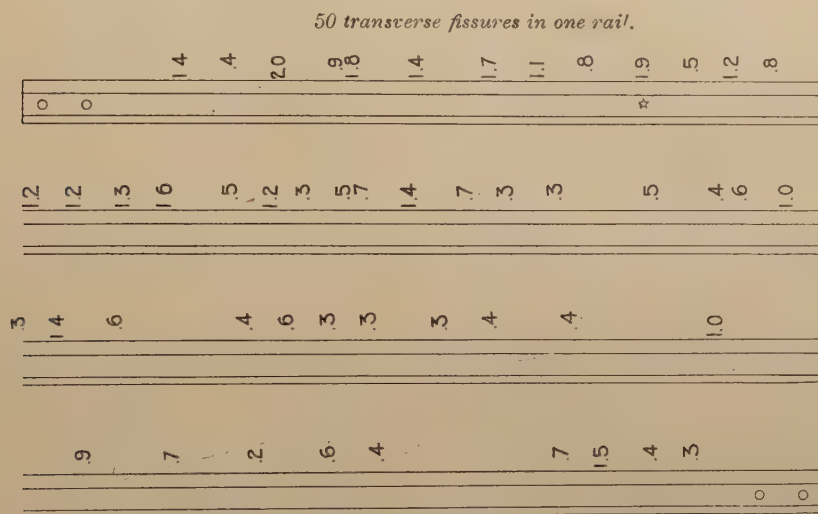


Fig. 53. — Fifty transverse fissures in the same rail.
90-pound rail about 14 years in service.

This was a 90-pound rail, which had been in the track for a period of 14 years. The mill analysis for the heat was C. 0.72, Mn. 0.75, P. 0.033, S. 0.036, Si. 0.20. It had the ingot letter E or F. Examination showed a shattered core in the center of the head, in which zone at least some of the transverse fissures had their origins. There was no abnormality in microstructure nor foreign inclusions associated with any of the fissures examined. The aggregate area of the fifty-odd transverse fissures was four times the entire sectional area of the rail.

Transverse fissures disclosed by shock tests.

In cutting rails to length in the reclamation yard of the St. Louis-San Francisco Railroad, Mr. J. G. Taylor, special engineer, effects rupture by endwise shocks. Starting a crack in the rail by nicking with a chisel, rupture is completed by striking the end of the rail with a sledge hammer. The longitudinal vibrations set up by the shock of the hammer are adequate to complete the fracture of the rail, an exterior crack of

limited extent having been made by the chisel.

Shock tests were made upon a section of a rail which displayed a transverse fissure in the tracks of the Chicago & North Western Railroad. This was a Gary rail rolled in October 1912, weighing 100 pounds per yard. The section experimented upon was 9 ft. 10 in. long, one end of which was hot sawed; the other end had a transverse fissure, 1 1/2 inches in diameter, displayed in the track.

There were surface indications of two additional transverse fissures in this section, which approached very near the periphery of the head. The section was therefore an eligible one upon which to repeat the shock test of the St. Louis-San Francisco Railroad. There was a third transverse fissure in this section of rail the presence of which was unsuspected, but which the shock test disclosed.

The hot sawed end of the rail was struck with a 10-pound sledge about 20 sharp blows, whereupon the rail separated near the middle of its length at a transverse fissure having a diameter of 1 1/2 inches. The surfaces were bright and silvery.

Resuming the test, a few additional blows of the sledge caused the rail to separate at a transverse fissure located 20 inches from the hot sawed end. It had a diameter of 1 3/4 inches, the surfaces being bright and silvery. There were no surface indications of the existence of this transverse fissure prior to the shock test.

Again testing one of the longer fragments, two blows of the sledge caused the rail to separate at a transverse fissure located 15 inches from the fissure which was displayed in the track. The surfaces of this fissure were also bright and silvery.

Thus, it happened that three transverse fissures were displayed in this piece of rail by means of endwise shock, striking the rail on end with a 10-pound sledge.

In the second test there was a notice-

able change in the pitch of the note emitted by the rail after a few blows of the sledge. Before rupture was completed the pitch of the note was much flattened, clearly indicating progressive fracture under the vibratory strains.

The longitudinal vibrations, concentrated and intensified at the edge of the interior fissures, caused rupture which under conditions of static load would have required several hundred thousand pounds gross stress. These transverse fissures each comprised about 20 %, the full sectional area of the rail or 40 % the sectional area of the head.

Certain longitudinal strains would be expected to accompany the vertical wave motions experienced in the track, and become factors in promoting rupture. Indeed the presence and influence of longitudinal vibratory strains seems essential to aid in reaching final rupture when the area of unruptured metal above the transverse fissure has become much reduced. Upon such an hypothesis high speeds would become active factors in the development of transverse fissures.

In ordnance engineering it is held that longitudinal wave motions traverse the chase of a gun in advance of the projectile and are reflected in such a manner that the normal radial strains from the powder pressures are increased. At high rates of speed a wheel traverses the length of a rail in about 1/3 of a second of time, a rapid movement but not comparable to the rate of travel of longitudinal vibrations in steel. It is conceivable that high speeds, as well as intense impinging wheel pressures, each contribute their share toward the development of transverse fissures, and that bending stresses in a rail which sufficiently weakened may share in its final rupture.

The detection of partially developed transverse fissures.

Transverse fissures in the tracks before final separation of the rails are

at times discovered. Fine hair lines appear on the side of the head, commonly on the gauge side, where vertical cracks separate the peripheral metal. Prior to complete separation a rust streak may appear, indicating the approach of a transverse fissure to the surface of the head. Careful scrutiny is necessary to detect these premonitory signs, which do not appear until complete fracture is close at hand. Some surface manifestation is, of course, necessary to admit of macroscopic detection.

When thousands of rails each year display transverse fissures it is a matter of grave importance respecting safety of travel to acquire some definite information upon their presence in rails in the track in their early stages of development. Derailments due to transverse fissures are rare in which the initial break in the rail does not show a fissure having darkened surfaces; that is, a transverse fissure which had not broken through the peripheral surface of the head, admitting air and acquiring darkened surfaces. It follows that all such fractures were possible of detection before the derailment occurred. The possibility of detection, however, may have been limited to an interval of time of very brief duration, too short to be of practical value. There are physical limits to track inspection, and the detection of rails which are on the immediate verge of rupture yields a margin in safety too slender to commend itself.

It is customary on some railroads to remove from the track all rails of a heat in which a certain number have displayed transverse fissures. Under the rules established by one State such removal is mandatory when three rails have displayed transverse fissures. The promulgation of such a rule carries with it, by implication, the assumption that some inherent defects exist which permeate the entire heat. The physical condition of the rails thus removed, however, does not appear yet to have been

the subject of inquiry. From the standpoint of economy it is not justifiable to remove thousands of rails upon unsupported suspicion. By implication, also, such rules place responsibility for the display of transverse fissures upon some indefinite, undefined property of an entire heat upon which no evidence has yet been discovered. Some inspecting engineers go a step farther and assume that individual ingots differ essentially in their tendencies to display transverse fissures. Vagueness prevails in the foundations of such beliefs, which attach to no known physical property. The only definite feature is the assertion itself that some heats of steel display transverse fissures while others do not, or have not under identical conditions of service.

The detection of the presence of transverse fissures in their early stages of development presents a tangible subject for discussion. Devices which have been offered are of two classes, those which depend upon variations in magnetic properties and those which depend upon differences in electrical resistance. No practical results appear to have been reached with magnetic devices, and contingencies are such that none would seem to be expected. Nearly 50 years ago extravagant expectations attached to the subject of magnetic testing which subsequent information indicated was fallacious.

The possibilities of an electrical resistance method was definitely shown in a demonstration made by Mr. Elmer A. Sperry in the year 1923 or early part of 1924. Experiments were conducted upon a model in which an interior air gap had been prepared, representing in effect a transverse fissure. The location of the air gap was indicated by Mr. Sperry's device, who at that time expressed the conservative belief that an internal transverse fissure equal in area to 15 % of the head could be detected by his apparatus.

Since no transverse fissure of that limited size has come to notice as the primary cause of a derailment it necessarily followed that the detection of such fissures in the track and those somewhat larger in size would be the means of averting accidents due to the development of this type of fracture.

It then definitely appeared that a device had been presented for the first time which made it possible to detect in rails in service this most insidious and dangerous type of fracture. Such a device opened great possibilities, marking a most important advance in research work and achieving success in a line of work directly associated with safety in travel.

The results of the demonstration made by Mr. Sperry in 1923 did not immediately attract favorable attention from the users of rails. However, after the lapse of some three years the matter was taken up officially by the users of rails and an appropriation made for the fabrication of an apparatus for the tests of full-sized rails.

The Sperry electrical resistance amplifying transverse fissure detector.

The honor of devising an apparatus capable of detecting the presence of danger lurking within the head of a rail was thus reserved for Mr. Elmer A. Sperry. Among safety appliances its position is unique. Safety in travel is menaced by a type of fracture which develops in the heads of rails, to which the terminology transverse fissure has been applied. It is a hidden danger. Other safety appliances deal with visible elements of danger, this with unseen danger.

Recent demonstrations with the Sperry detector have shown it capable of indicating the locations of transverse fissures in different stages of development from those in area less than 2 % the area of the head up to those which have separated the major part of its cross

section. Conversely, certain rails each of which has displayed a transverse fissure in the track and have been shown by the detector to contain none other, the most diligent search for an additional fissure has been without avail. The detector differentiates the interior fissures according to their sizes.

The Sperry detector opens the way for the acquisition of accurate information upon the structural state of steel rails not realized in any other device yet presented. In addition to locating transverse fissures in rails in the track, the detector is, of course, available for the examination of rails of heats which have been removed from the track on suspicion of containing incipient fissures. Furthermore, the detector would be serviceable in the examination of rails heat treated to ascertain whether such rails had interior cracks oriented after the manner of transverse fissures or contained shrinkage cracks of magnitude.

The Sperry detector signalizes the most important step forward — in fact, the only one of its kind — during the period of 16 years since this type of rail fracture came into prominent notice.

Origins of certain fractures in rails under drop tests.

Reference has been made to the proper reading or interpretation of fractured surfaces. The first consideration which should be given fractured material is to note the location of the origin of fracture and trace the direction in which the line of rupture progressed. Explanations which account for the fracture of a rail must be in harmony with the evidence presented by the fractured surfaces. The ease with which fractured surfaces may be read should be familiar to all whose duties connect them with such occurrences.

Steel fractures usually have their origins defined by easily recognized nuclei, from which emanate radiant lines. The

name « starring » has been given such appearances. The extension of a line of rupture along a narrow section of metal is illustrated by a fanlike appearance.

Steel rails broken by bending tests or under the drop commonly show the exact points at which the fractures had their origins. Rails struck on the head with the falling tup of the drop test are expected to have the origins of their fractures located in some part of the base, and when broken in reverse direction to have their origins in the head. Fractures do not always originate in the most remote fibers from the neutral axis of the rail. In new rails their origins are seldom in the most remote fibers.

Slightly decarburized surfaces increase the toughness of the outside fibers and lead to fractures of interior origins. Abrupt changes in cross-section dimensions lead to fractures having their origins at the fillets of the web, especially in rails of the heavier sections. Dog marks in the web have located incipient points of rupture. A slight chisel nick in a flange will lead to rupture starting from the nick. Dropping the wheels of a hand car and indenting a flange will lead to the same result. Small holes for bond wires inadvertently drilled in the flange will lead to the fracture of the rail. A change in structure of the steel accompanied by the introduction of internal strains such as the brazing of bond wires at the junction of the web and the base will lead to rupture under service conditions, some of these features having been previously referred to.

Figures 54 and 55 show the location of fractures of some rails which were broken under the drop. Stars placed on the cuts above or below the origins of the fractures indicate the locations of the incipient points of rupture. The starring effects in the heads of two rails are illustrated by figure 54, one

of which is eccentric, the other at the center of the head. Transverse fissures might, in the course of time, start at each of such places. It would be erroneous, however, to designate these as incipient fissures. A silvery crescent or silvery oval identifies a transverse fissure. The initial separation of the metal at a transverse fissure presents the same appearance as the initial point of separation of a tensile test piece. At their periods of inception tensile test pieces and transverse fissures are necessarily alike, each being a tensile fracture. Shrinkage cracks are also tensile fractures.

Figure 54 illustrates starring effects in the bases of two rails, and a portion of the surface of a third rail the fracture of which originated under the head. One of the base fractures was eccentric with reference to the web, and at the middle of the depth of the flange at that place. The other base fracture originated at the middle of the width of the base, at its lower surface.

Arrows indicate the directions in which the several fractures traversed the cross sections of the rails. The cuts do not clearly show the characteristics of the fractured surfaces which on the rails themselves were very pronounced.

A few notes on the fabrication of steel rails.

Critical comments appear from time to time upon mill practice including both the making of the steel and the rolling of the rails. The trend of such comments has been to place the responsibility for the display of transverse fissures upon the steel manufacturers. The extreme vagueness and intangibility of the comments are obstacles to their investigation. Rails are made in shapes in strict conformity to templates. Specifications governing their chemical composition are met. The amount which a rail shall contract in cooling from the hot saw to atmospheric temperature is

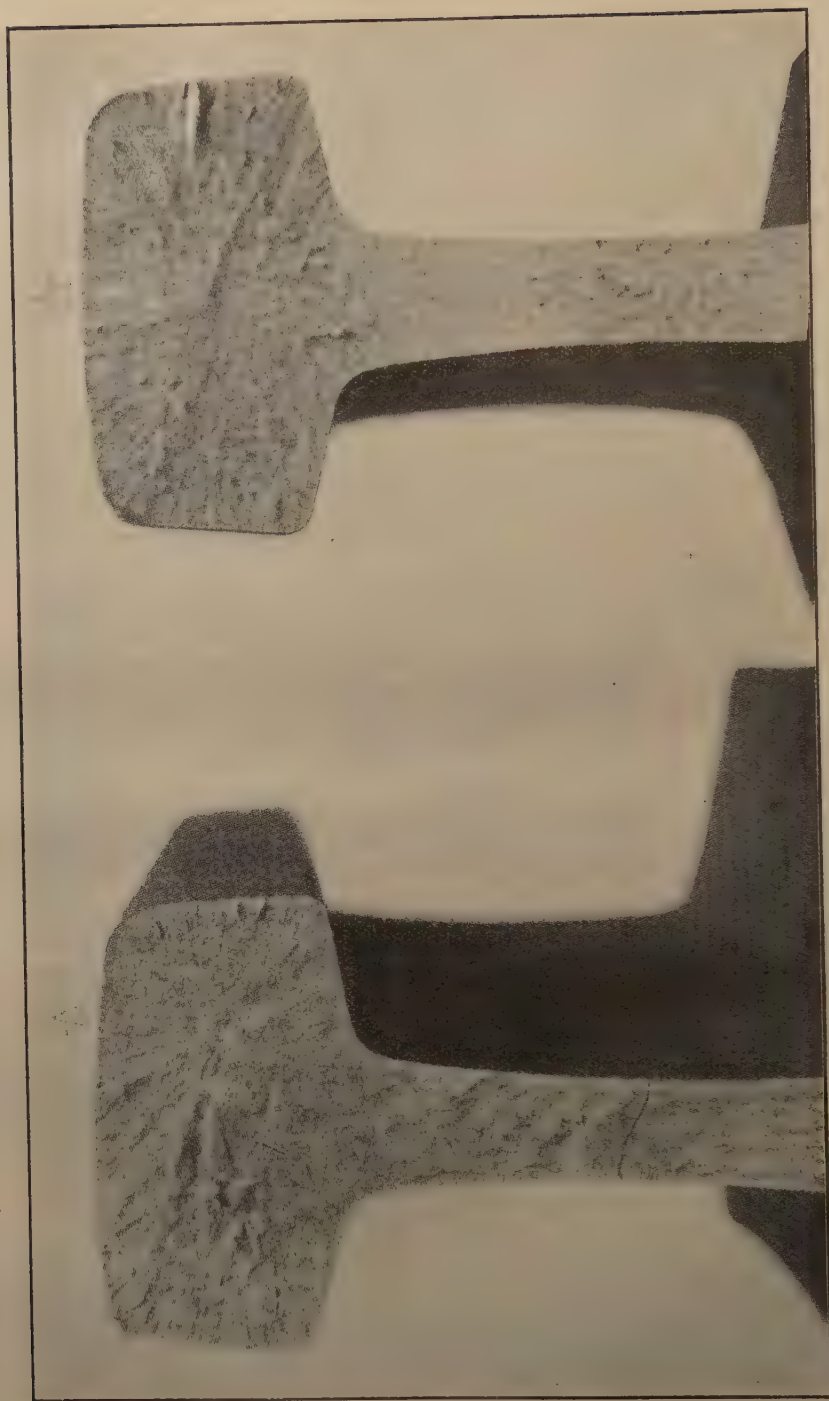


Fig. 54. — Starring effects in the heads of two rails.

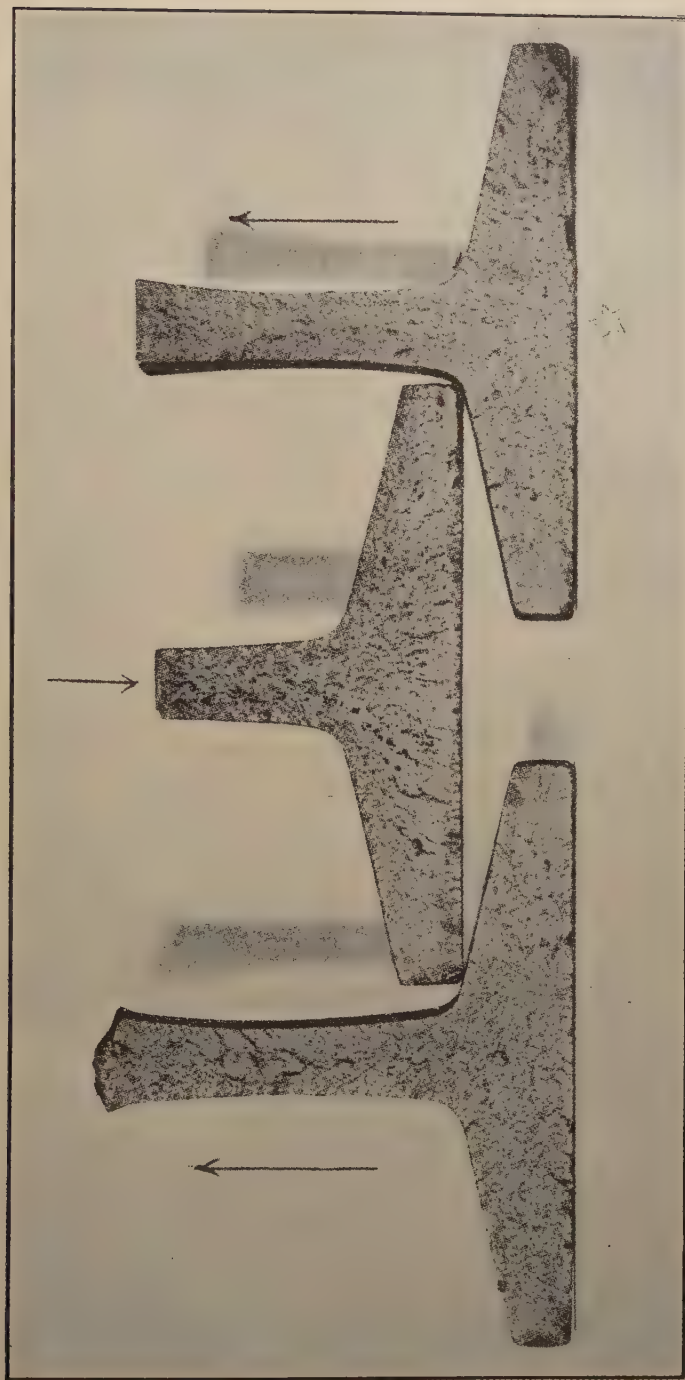


Fig. 55. — Starring effects in the bases of two rails. Fracture of third section originated under the head.
Arrows indicate the directions the lines of rupture followed.

often prescribed. A limit is at times placed upon their straightness prior to gagging. Drop tests are made, and a final inspection for surface. These are features which rail makers are called upon to meet. If a relation is established between the chemical composition and primitive physical state of the rails and their endurance of track conditions such information must come from the users of the rails. The opportunity to acquire such information is not at the open hearth furnace nor at the train of rolls of the rail mill.

The making of steel as well known is conducted on a colossal scale. The handling of great quantities of raw material is an every-day occurrence. Necessarily the process is one which practically must be under complete control. Current discussions of open-hearth operations among steel makers refer to refinement of details not departures from general practice.

From the ore to the finished rail the different stages of fabrication are conducted with system and regularity. Ore reduced in blast furnaces to pig iron is

conveyed to a mixer, a reservoir of hot metal. For weeks or months hot metal is intermitting charged and with-drawn from the mixer in its passage from the blast furnaces to the open-hearth furnaces.

At the open-hearth furnaces the interval of time in making a heat of steel may range from 10 to 11 hours. This interval of time includes throwing in limestone for slag-making purposes, charging cold steel scrap, charging hot pig iron from the mixer, furnace additions of ore and flourspar; recarburizing metal, and ferro-manganese when ready for tapping, ferrosilicon being added to the metal when in the ladle.

Quantities handled in making a typical heat would be something like the following: Limestone, 28 000 pounds; scrap, 121 000 pounds; cold metal, 14 000 pounds; hot metal, 105 000 pounds; recarburizing metal, 35 000 pounds.

The precision with which the chemical composition called for by specifications under which rails are being furnished and the composition attained are given in the example which follows:

—	C.	Mn.	P.	S.	Si.
Composition called for. . . .	0.64 to 0.77	0.60 to 1.00	0.040	...	0.15
— attained. . . .	0.64	0.72	0.031	0.032	0.16

The particular heat to which the above figures refer, furnished 50 ingots, 19 by 19 inches each. It would be fantastic in the making of this heat to predict its relation to the ultimate display of transverse fissures in the rails into which it would be rolled, or which particular ingot of the 50 would be prone to display such a type of fracture.

In the rolling of the ingots of one heat into rails the speed of rolls and reductions in the several passes would not be unlike the rolling of other rails of the same weight. If rail-mill conditions exert an influence on the formation of

transverse fissures, that influence should extend to all rails. The reduction of an ingot requires the expenditure of mechanical work, the energy required increasing with the speed of reduction. Work is done in overcoming plastic resistance of the hot metal.

In the forming passes the mechanical work would vary in different parts of the cross section of the derivative shapes. The mechanical work done on steel at the higher temperatures has little if any influence on the physical properties when cold. However, as atmospheric temperatures are approached the

mechanical work done on the steel has a decided influence on its final properties.

Throughout the passes of the rail mill the head of the rail remains at a higher temperature than other parts of its cross section. If cold rolling, in the mill sense, promotes the formation of transverse fissures, they would be expected in other parts of the rail than where they are prevalent.

Investigations conducted by the bureau of safety have shown no inherent reason for attaching responsibility for the display of transverse fissures to manufacturing conditions, either in the making of the steel or in the rolling of the rails.

Results of a questionnaire submitted to representatives of leading railroads and steel mills.

That different points of view have been taken by the railroads and the steel makers has been patent to all. To aid in bringing about a better understanding between steel makers and the users of rails and establish upon what features they were in a state of mutual accord, and by elimination ascertain upon what points differences of opinions attached, a questionnaire was prepared and presented to representatives of leading railroads and steel mills. Replies thereto were tabulated and brought before these representatives at meetings participated in by them together with the bureau of safety.

The questionnaire took up matters of fact, in a general statement of transverse fissures; references were made to manufacturing conditions from the ingot to the last pass of the rail mill; presenting the subject of gaging, acceptance tests, drop tests; the effects of aging on the physical properties of rails; track conditions and their effects on rails; on the relations of manufacturing details to the formation of transverse fissures; concerning an item in the program of the American Railway Engineering Associa-

tion of 1924 (having reference to permissible wheel loads); carbon steel rails of higher manganese content; interrogatories having reference to a 90-pound rail in which a large number of transverse fissures were displayed; and in conclusion a count in the questionnaire which read: « Have you identified any manufacturing condition (omitting consideration of shattered zones) which you regard responsible for the display of transverse fissures? »

Beneficial effects seemed to result from the presentation of the questionnaire. Definite questions brought out definite replies, revealing the fact that upon many features, those which were most essential, no practical differences in points of view really existed. It was concurred in that no foreign inclusions of any kind were at the nuclei of transverse fissures, furthermore that the microstructure of the steel at and in the vicinity of a transverse fissure did not display any peculiarity not found in other parts of the steel. It necessarily followed that there was no manufacturing condition to be identified where neither any foreign inclusion, abnormality in structure, or chemical composition was to be found; hence the replies to that count of the questionnaire were negative.

It is, of course, well known that steels in general are streaked in some degree and that the streaks exert an unfavorable influence on some types of fracture. Slag inclusions, or, more properly, silicates, are present in acicular lines which constitute lines of structural weakness. Such lines lead to split heads. When the split head fracture is vertical it does not seem to influence a transverse fissure. When the split head is horizontal it may lead to a compound transverse fissure.

Repeated alternate stresses.

In regulating the loads which are put upon metals the results of laboratory

tests on repeated alternate stresses furnish useful information. The basic feature in all engineering practice refers to the matter of ultimate endurance of the materials employed. It is believed there is a limit in the ability of steels to endure stresses, a stress of a certain magnitude below which the metal possesses unlimited endurance. In repeated alternate stress tests the line of demarcation between limited and unlimited endurance of stresses in steels is seemingly well defined.

Illustrating this feature, using the results of tests on a steel of 0.82 carbon content, the tensile test of which gave an elastic limit of 64 000 pounds per square inch, tensile strength, 142 800 pounds per square inch, elongation 7 %, contraction of area 11.8 %, the relative ability to endure stresses of different magnitudes were as follows :

Under repeated alternate stresses of 60 000 pounds per square inch, let an ordinate of 1 inch graphically represent the endurance of the metal. At 45 000 pounds per square inch the ordinate representing its endurance would then be 16 inches in height. With a further reduction of stress of 5 000 pounds per square inch, the ordinate at 40 000 pounds per square inch would have a height of 452 feet, and the latter without reaching final rupture of the metal.

Corresponding results would no doubt be displayed by steel in whatever positions it may be used. Steel rails have their defining stresses below which they would display unlimited endurance, but such loads on wheels would be so low as to preclude their consideration. It should be definitely impressed on the minds of all that track conditions impose overstraining forces. The rail problem is to find the steel which will endure overstraining forces of longest duration without rupture. Answers to this question must come from the track.

Concluding remarks.

In this report circumstances have been described relating to the accident which is its main subject. The accident was caused by a transverse fissure in one of the rails of the track. In the reports of this bureau other accidents have been described which resulted from transverse fissures. On the present occasion there was no essential difference in respect to the fracture of this rail over others which have taken place. The present accident was characterized by reason of the large loss of life and personal injuries which it caused.

The surfaces of the transverse fissure first shown had lost their silvery luster and were darkened, indicating that it had reached the surface of the head of the rail prior to the time of the accident. In other derailments of this kind the transverse fissures had reached a corresponding stage in their development. Strictly speaking there was a possibility for the detection of the fissure and the accident being averted, but not a probability of doing so. The engine of the derailed train doubtless completed the fracture of this rail, although this transverse fissure had reached the surface of the head before this train entered upon it; how much earlier can not be said.

The rate of growth of a transverse fissure is a matter of extreme importance to acquire information upon, but obviously can not be told from surface inspection. For a period of 16 years — that is, since a transverse fissure was recognized and described as a distinct type of rail fracture — information upon its rate of growth has not been at hand. Opportunity or means for acquiring such information appears to have been presented some three or four years ago but unavailed of; reference is now being made to the Sperry transverse fissure detector.

The detection of transverse fissures in rails in the track and measure of their relative sizes seems to be accomplished

in the device above mentioned. This accomplishment comprises one of the most important features connected with the display of transverse fissures. It is desirable to ascertain what degree of severity in service conditions lead to the formation of this type of fracture. Transverse fissures prevail in some localities; they are unknown in others. In locations where they prevail, the relation of definite service conditions to their display has been shown.

On some roads their distribution is quite general. On others they are segregated within narrow limits, apparently influenced by local conditions.

In respect to their avoidance or overcoming the formation of transverse fissures the outlook is not promising. In fact, no encouragement whatsoever is presented. Intense study has not yet detected any specific cause for their prevalence in one heat of rails over another of similar composition, nor why from a metallurgical point of view one rail should display a transverse fissure after a very brief interval of time in the track and another endure for a long period. It is logical to assume that phenomena of this kind depend upon something else than a consideration of the initial physical properties of the rails themselves. The factors to be given consideration are the strains and stresses to which the rails are exposed. If proof attaches the causes of fracture to conditions of service, no other consideration is necessary to explain the reason for the prevalence of fractured rails. It may be said that practically all of the ordinary conditions of service expose rails to destructive influences. This member in the track structure is habitually called upon to resist destructive forces. If all parts of the cross section of a rail were exposed to the maximum strains which some parts are, there could be no such a thing as track structures as we now have them. The possibility of maintaining a track relies upon the reinforcement of the

overstrained portions of the rails by the understrained parts.

Two principal features are presented in the track-structure problem; one is to find the steel which has the greatest endurance to track stresses; the other is the detection of incipient fractures, whether they are transverse fissures or other types of fracture. The review of the physical properties of steels introduced in the present report together with the description of those inherent to all steels enumerates features which are of common observation. Practically all the vicissitudes to which steels are exposed are encountered in some degree by rails in service. For the most part they are features which manufacturing conditions do not deal with.

Specifications governing the acceptance of rails perforce can not prescribe against the effects of destructive forces. They can only call for certain primitive properties in the finished rails. If service stresses are confined well within the primitive physical properties, prolonged endurance will be realized. Since service stresses of rails do commonly transcend those critical limits prolonged endurance can not be expected.

In answer to the question what causes transverse fissures, the reply is a brief one. They are caused by the introduction of internal strains in the head of the rail set up by the action of the wheel pressure on the running surface of the head. The internal strains directly introduced are strains of compression. To resist these strains of compression the metal next below is put into a state of tension. Transverse fissures are formed in that zone of metal which is put into a state of tension. These words virtually repeat the explanation which was given in the report of the commission on the Manchester accident on the Lehigh Valley Railroad of 25 August 1911.

To the query, why do some rails display transverse fissures while others do not, or have not, the general reply is equally brief. Rails differ in their

ability to endure stresses. If the reason is not shown in their physical properties or structural state, it is presumptive evidence they have been exposed to different orders of treatment. The physical properties of steel are not inconstant or capricious, but questions of durability under varying stresses are among those which are most difficult to explain. The difficulties are enhanced by the absence of exact knowledge of what stresses are under consideration.

Reliable track records yield the most promising data in the final summation of the endurance of rails. Recognition of what constitutes the most desirable chemical composition in rail steel must come from track records. In perishable material greatest value will attach to those means or the device which will give the earliest warning of impending danger.

At present there is no remedy known for the prevention of transverse fissures, current track conditions being considered. It seems, however, that the matter of their detection has been solved, constituting the greatest accomplishment yet heralded.

Suggestions.

A report of this kind would hardly be complete without appending some suggestions or recommendations intended to improve present conditions. A few features will be enumerated which have a direct relation to the serviceability of rails, while reference will also be made to some physical phenomena which might properly be made the objects of advance study.

Remarks will be introduced under three general headings :

1. Steel making and the fabrication of steel rails.
2. Railroads or the users of steel rails.
3. Research problems.

1. Steel rails would be improved against the display of certain common types of fracture by the elimination of both internal and external seaminess. Internal streaks or seaminess in the head and external seaminess at the lower surface of the base are two critical parts in the cross section of a rail. Improvements at these two places would prolong the lives of certain rails.

Generically split heads and base fractures belong to the same type of rupture. Each results from the influence of a lateral force and each has its origin at a longitudinal seam or streak.

Impinging wheel pressures set up simultaneous strains in two directions in the top of the head. One component tends to form transverse fissures, the other to form split heads.

When lateral flow of the metal of the head encounters a slag or silicate streak, opportunity is presented for the formation of a split head.

In the metal of the base crosswise service stresses in the flanges lead to longitudinal fractures which originate at seams or laps.

After the same fashion that longitudinal cracks in the base are diverted and form crescent-shaped fragments, horizontal split heads are diverted from their courses and form compound transverse fissures. Vertical split-head fractures lead to the separation of the head from the web.

These two causes of rail fractures, internal and external seaminess, furnish problems for the steel mills to overcome or minimize.

Shrinkage cracks, in the heads and bases of rails, when and under what conditions they reach a maximum and rupture ensues, essentially constitute a research problem.

2. The railroads occupy a favorable position to acquire data upon the longevity of rails in respect to the display of transverse fissures. Material is at hand for comparing the properties of rails

which have displayed transverse fissures at widely differing ages. The problem is to ascertain whether any physical, structural, or chemical factor is responsible for the variable behavior of rails in the track or whether differences in longevity are due to undefined track stresses.

3. Research problems specifically referring to steel rails, or in fact to steels in general, are somewhat numerous. Basically, steel can be used for rails, because it is capable of acquiring and retaining internal strains. They are necessarily both of tension and compression. Of what does this common property consist? Can the presence of a strain, positive or negative, be recognized in any other manner than by permitting its release?

Exhaustion of toughness may be reached with or without distortion of the grains. By what means can exhaustion of the ability to permanently elongate be recognized without subjecting the steel to its limit of ultimate resistance?

When changes in density occur, what are the interrelations of the microconstituents? These and kindred queries present themselves in studying the mutual relations, causes and effects, of wheels and rails. Information upon these basic features would be a contribution to the physics of steels in whatever situation this important metal is used.

Respectfully submitted.

JAMES E. HOWARD,
Engineer - Physicist.

[625 .13 (.73)]

Tunneling at Musconetcong now and fifty years ago.

Figs. 1 to 19, pp. 344 to 356.

(From *Engineering News-Record*.)

« A notable contrast in tunneling methods and machinery is furnished by the description of parallel tunnels through Musconetcong Mountain in New Jersey. One tunnel was begun in 1872 and was completed in 1875; the other was begun in 1926, is now under construction, and will be completed in 1928. On the same railway, scarcely two rods apart, through identical rock strata, of almost equal length, but separated 54 years in date of construction, these tunnels enable comparisons rarely afforded by such engineering work.

« Virtually, mechanized tunneling methods first became accepted practice at old Musconetcong. In the new tunnel

mechanized tunneling in its most advanced manifestations is exemplified. The change in half a century is of curious interest in that it demonstrates high enterprise and skill in the perfection of tunneling tools and materials rather than striking advance in rock tunnel construction processes in that time.

« As the story is largely one of equipment development, illustration has been employed profusely both to emphasize the broad fact of increased mechanization of tunneling and to enable comparisons of the machines of today with those in use half a century ago. » (Editorial note, *Engineering News-Record*.)

Old Musconetcong tunnel was built in 1872-1875 to give the Lehigh Valley Railroad, then terminating at Phillipsburg, N. J., on the Delaware River opposite Easton, Pa., an exit to tidewater through Musconetcong Mountain, one of the high ridges of western New Jersey. This new tidewater extension, built as the Easton & Amboy Railroad, ran to Perth Amboy on Raritan Bay. The tunnel was the outstanding construction task. It was 4829 feet long, with a rock section 21 feet high and 26 feet wide, for two tracks. With growing car and locomotive sizes, the tunnel finally could not

pass two trains and was changed to single track. Meanwhile, the railway to the tunnel both ways had grown to four tracks. Obviously, the constriction of the mile of single track had to be reduced and in time a new Musconetcong tunnel was decided on — a two track tunnel 30×25 feet in section and 4840 feet long, parallel to and 130 feet south of the old tunnel. This is the tunnel now being constructed. Compared with the old tunnel, the greater cross-section is the only broad difference in general engineering design introduced to meet modern traffic requirements.

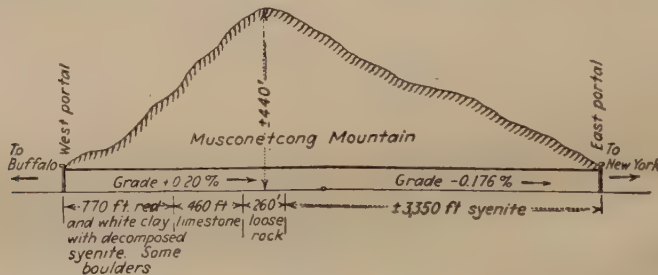


Fig. 1. — Profile of Musconetcong Mountain showing ground penetrated by new tunnel.

Virtually the same strata, except that at the west end they contained great volumes of water, were penetrated by the tunnel constructed 1872-1875.

Location and materials.— The diagram profile (fig. 1) of the new tunnel indicates the materials penetrated. The ground penetrated by the old tunnel developed great volumes of water, whereas the new tunnel workings, in identical material, are comparatively dry. The only water trouble to date was caused by striking a flow of about 300 gallons per minute in the north plumb-post drift on the west end at the junction of soft ground with limestone, which flooded the workings, causing two days' delay. The flow is now about 200 gallons per minute, and is handled by the continuous operation of pumps. The syenite is a hard rock but blocky enough in places to require timbering to guard against roof falls. Where the syenite joins the limestone, the rock is loose and has to be heavily

timbered. The limestone itself is reasonably stable but shows many cavities. From the solid limestone west to the portal, the mixture of clays and decomposed syenite is very difficult material to tunnel; it develops enormous pressures and is highly unstable when wet. It has been in this material and in the zone of loose rock that virtually all of the heavy work in the new tunnel has been encountered.

In the old tunnel the cavernous limestone held water pent up in numerous cavities. This water gave much trouble, as is described farther on. The old tunnel, however, drained the rock so that when the new tunnel came to the limestone it was, except as stated, comparatively dry. Indeed, water gave no serious trouble in the new tunnel, nor

did it in the old, once the limestone reservoirs had been drained. This drainage, however, proved a nerve-breaking task in the old work.

Access, power supply and plant. —

The new Musconetcong tunnel has a four-track railway coming to each end of the work. Access for materials, supplies and equipment, therefore, was no problem beyond siding and spur construction and some trucking of cement and camp provisions and for the interchange of supplies between ends. When the old tunnel was begun there was no railway nearer than a mile from the west portal and five miles by overmountain roads from the east portal. All materials and supplies had to be hauled these distances by teams; this hauling kept busy for nearly three years 24 four-horse teams. The comparatively little hauling by highway for the new tunnel is by motor trucks; and the men come to work, go to town and cross the mountain from east camp to west camp, by automobiles. This has been the change in highway haulage between old Musconetcong and new Musconetcong.

The new power is quite a revolution. At the old tunnel, steam operated every prime mover. It is stated that 1 000 tons of soft coal and 26 500 tons of anthracite coal were used for steam generation and blacksmithing operations. On the new work the prime movers are electric motors. A 7-mile transmission line brings in 33 000 volts from the New Jersey Power & Light Co., and transformers at the west portal step this current down to 2 300, 220 and 110 volts. All equipment except the steam shovels for approach cut excavation is operated by electric motors or by compressed air generated by motor-driven compressors. The steam shovels, when shifted into the tunnel for mucking, were changed to compressed air. Pumps and hoists in the tunnel are air-operated. A 200-H.P. motor operates

each of the four compressors. Air is used to blow the oil forges and operate the drill sharpeners. Electricity lights camp and plant buildings and the tunnel workings; it drives the 4 000-cubic feet per minute blowers which force fresh air through 18-inch pipes to the working faces. These forms and applications of power are not notable from the standpoint of present practice, but are named merely in comparison with the power equipment of some dozen or more steam boilers employed in the old tunnel workings.

The comparison of tunnel construction equipment exhibits greater similarity. Compressed-air drilling and high explosives were first used in tunneling in America on the Hoosac tunnel but only in part of the work. Liquid nitroglycerin was the explosive. The Nesquehoning tunnel in Pennsylvania was the first to employ compressed-air drilling throughout, but the blasting was done with black powder. At Musconetcong there was complete mechanization of drilling operations and dynamite was the explosive, its first regular use, it is believed, for tunneling in America. Indeed, power equipment was used generally for the first time at old Musconetcong — it was the pioneer in modern rock-tunnel planting practice. Writing in 1875, Henry S. Drinker, then resident engineer on the tunnel and later author of the great American classic on tunneling, said of the construction plant: «The contractor had in use the latest and most approved machinery.» A comparison of main plant items then and now is made in the accompanying table. Aside from differences in capacity and perfection of machines, the outstanding differences are electric operation and the concrete mixing and placing equipment. The particulars of comparative equipment are given in succeeding sections, working from rather scanty records of the old machines found in contemporaneous publications.

Plant items at old and new Musconetcong tunnels.

Only main items are scheduled, without indicating capacity or output, merely to illustrate mechanization.

Old Musconetcong 1872-1875.

- 26 Ingersoll drills.
- 4 Burleigh and 4 Rand-Waring air compressors, steam-driven.
- 13 locomotive boilers supplying steam to all plant except steam shovels.
- 2 steam shovels for west approach cut.
- 2 locomotives handling spoil trains.

Hoisting engines, pumps, derricks, repair shops, job and camp structures and miscellaneous tools.

New Musconetcong 1926-1928.

- 30 Ingersoll-Rand drills.
- 4 Chicago Pneumatic Tool Co. compressors, belt-driven by electric motors.
- 7-mile transmission line carrying 33 000 volts; power for all plant except excavators.
- 2 steam shovels and 1 dragline for approach cuts and mucking.
- 8 locomotives handling spoil and concrete trains.
- 2 concrete mixing plants.
- 2 pneumatic concrete placers.
- Drill sharpeners, compressor after-coolers and ventilating plants.
- Hoists, pumps, derricks, shops, camp and miscellaneous tools and outfits.

Approach cuts and start of headings.

— About 370 000 cubic yards of material had to be taken out for the approach cuts for the new tunnel. These cuts were about 75 feet deep at the portals, the longer cut being at the west end. The records at hand of the old tunnel cuttings do not give quantities but probably these were not very much less than those for the new tunnel. Depths and materials of excavation were certainly about the same. The interesting fact is that in general the same methods of excavation were employed in the two operations over half a century apart — steam shovel excavation and train disposal. Accounts of the old work are meager in information concerning the approach cuttings but on the west approach two steam shovels « ran day and night » and with « two small locomotives » took out the cut.

In 1872-1875 Souther was the only maker of steam shovels and the Otis shovel was the only type, so these were probably the shovels used on the old tunnel. Even without particulars it is conclusive that they were puny machines compared with the railroad type steam shovels used, one at each end, on the new tunnel. These were modern railroad type shovels, both loading into

5-cubic yard dump cars hauled by 20-ton and 18-ton dinkeys and 16-ton gasoline locomotives. The dump car tracks were 3-foot gage. Gasoline locomotives and dinkeys all are of a day since the old tunnel was built. Only the roughest of performance comparisons is possible. On the west approach the two shovels on the old work made the cut to crown heading level in 19 months; the 70C shovel on the new work had got down to the crown heading in five months.

As it performed the important function of making the new tunnel a dry tunnel the west crown-heading and drainage work on the old tunnel calls for summary. With the long deep cutting, the engineer of the old tunnel thought to gain time by driving a slope to the tunnel and drifting both ways from it. This slope was inclined east to strike the tunnel about the middle of the limestone zone. Figure 2 serves to explain it and the subsequent drainage operations. The slope was begun in April 1872, and work proceeded well until drift 1 to the east had advanced 275 feet, and drift 2 west some 125 feet. Then on 7 May 1873, water under great pressure was struck in drift 1 and, against all the pumps available, flooded drifts and slope to within 120 feet of the top.

Increased pumping failed to lower the water much and on 14 May the slope timbering above the rock surface began

to collapse and the slope in earth 190 feet down was lost.

To meet this situation shaft 1 was

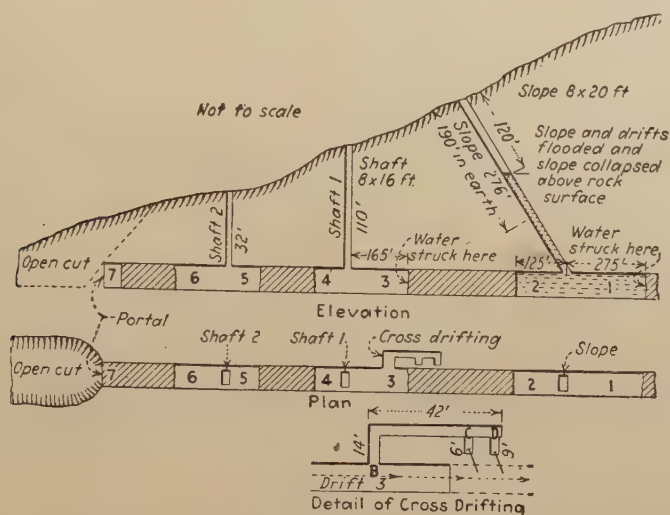


Fig. 2. — Diagram of crown drift operations in old tunnel.

These complex workings were resorted to for handling the water which repeatedly flooded them and ultimately delayed construction about twelve months.

started and reached grade, 110 feet down, on 21 June 1873. Drifting began east and west from the shaft bottom and on 13 August, when drift 3 was 165 feet east, water broke in and flooded the workings to a height of 40 feet in the shaft. No material change in water level in the slope followed, indicating that the second inflow was from a new source. Shaft 1 was pumped out on 19 August, on 22 August and on 9 September, each time followed by flooding as soon as any advance of drift 3 was attempted. Each time, however, this drift would dam up with sand, so that the workings could be laid dry. Work was then begun on shaft 2 and drift 5 on 13 September, and on 7 October drifts 4 and 5 were connected. This gave two shafts from which to pump.

Work was then resumed on drift 3,

but it again flooded and was pumped out 14 October. This time the dam was left and cross-cutting and parallel drifting were begun to tap the water ahead of the face of drift 3. At cross-cut C no water was struck and another attempt was made to advance drift 3 on 4 November. Again water came in, but it was dammed before the works were flooded. Then parallel drifting was resumed and at cross-cut D the drill hole tapped the reservoir on 8 November. After three days' pumping the pumps broke down and the drifts were flooded. By this time, 11 November 1873, the open cut had got down to crown drift level and drift 7 was started and connected with drift 6 on 20 November. With free vent the water spent itself in 40 minutes, running drift full. Thereafter the water in both the slope work-

ings and the shaft workings was ordinarily no more than could be handled by pumps and ditches.

As stated, the old tunnel workings laid the mountain dry and the new tunnel has had little water trouble. The crown drift on the new tunnel, however, started from the portals, as faster cutting by the big steam shovels laid the portals clear sooner than slopes or shafts could be put down. Cutting started 1 May 1926, and crown drifting on 1 September. These dates were the same at both ends.

Compressor equipment. — At the new tunnel identical compressed air plants are installed at both ends. Each consists of two 19×11×12-inch duplex compressors belt-driven each by a 200-H.P. synchronous motor. All compressed air is run through 3 000-cubic feet after-coolers with cooling water furnished by electric-driven centrifugal pumps.

The Burleigh compressor, developed largely on the Hoosac tunnel, was used at Nesquehoning and then at Musconetcong. It was known as a two-drill machine; the four compressors at the west end at Musconetcong actually operated nine drills of the type described later. The compressor had two vertical air cylinders whose pistons were actuated from a common crankshaft operated by a horizontal engine and a 45-H.P. tubular boiler.

The other type compressor, known as the Rand-Waring, used at the east end had been used at Nesquehoning; they were bought second-hand for the work at Musconetcong. One had a 16-inch cylinder and three had 12-inch cylinders, double-acting, with poppet valves and a water-cooling system. An oscillating steam cylinder operated the air piston through a crankshaft, connecting rod and crosshead. Five 50-H.P. locomotive boilers supplied steam for the four compressors.

Besides their contrast in compactness, the compressors of 1927 are different

machines in almost every compressor embodiment except the basic materials of construction and the compressing element of a power-driven double-acting cylinder and piston. Automatic cooling, regulation and lubrication common in modern compressors are new since the Burleigh and the Rand-Waring machines. Adjustability and replaceability of bearings and cross-heads, now common, are new. The enclosed type of main frame is new. Bearings and guides are larger; pistons are lighter and are packed to take up wear; cylinders are reborable; simple and light plate valves, with cushioned operation, have replaced poppet and Corliss types; cast steel replaces cast iron in crank disks; babbitt and bronze bushings, forced joints, forged and cold-rolled rods, ground and polished guides, and all materials and workmanship demonstrate improvement.

The motor end shows even greater changes. Then the steam engine was the only available prime mover. Now there are also the internal combustion engine and the electric motor. Quite as notable is the change in simplicity of power transmission from the motor to the compressor element. Finally the oscillating cylinder steam engine of the old Rand-Waring mixer is today as far out of consideration as the single acting compressor cylinder of the old Burleigh compressor. In the Rand-Waring compressor there appears, however, a forethought of today's objective of motor and compressor unit compactness.

Ingersoll drills were selected at old Musconetcong as representing rock drill design in about its highest development. This drill had been put on the market by Simon Ingersoll in 1870. A section of the drill, from an illustration of the period, shows its main characteristics. It has a 5-inch piston, which indicates altogether a pretty sizable and hefty contrivance, but it was selected because, among other reasons, it was lighter and handier than the older Burleigh drills

used at Hoosac and at Nesquehoning. At new Musconetcong the drills are Lyner-Ingersoll drifters — R 72, weighing 164 lb. Direct comparison is impossible because a change of principle is

represented — the old drill is a piston drill; the new is a water hammer drill. Roughly, the new drill is eight times as fast and requires half as many man-hours for shifting.

Fig. 3.

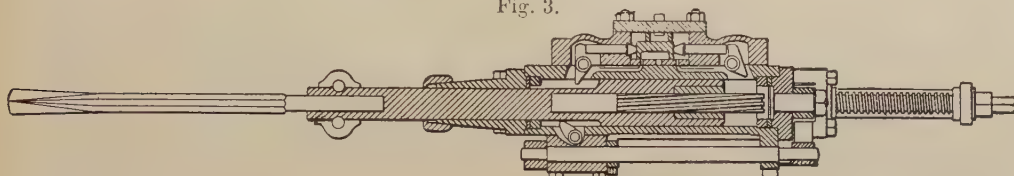
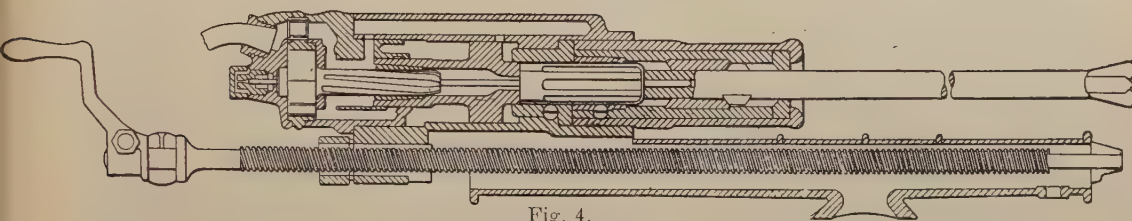


Fig. 4.



Figs. 3 and 4.

Fig. 3. — Ingersoll 5-inch drill used on old tunnel.

This type of drill was selected as being less cumbersome than the Burleigh drills used at Hoosac and Nesquehoning. It was its first use in tunnel work. This type of piston drill, improved in workmanship and design, continued in use until the hammer drill, after 1896, gradually replaced it.

Fig. 4. — Drifter drill used on new tunnel.

This drill, 30 or which were used during the construction of the new tunnel is eight times as fast as the first Ingersoll drills and can be shifted in half the time. It is the highest development as of this date by its makers of the drifter drill.

On the old tunnel all drills, both for bench and heading holes, were carriage-mounted, the practice and the general design of the carriages being taken directly from the Hoosac tunnel work. Sketches from old records (figs. 8 to 12) indicate the drill mountings and the drill-hole arrangement. In the new tunnel the drills are mounted on columns for the heading holes and on tripods for the bench holes. A view in the new tunnel heading and the drill-hole arrangement are given by the illustrations (figs. 13 to 18). Comparing the number,

depths and footage of holes, they were for heading in the old tunnel as follows :

DESIGNATION.	Number.	Depth, in feet.	Total footage, in feet.
Cut C.	12	10 1/2	126
First square-up (1) . . .	8	12	96
Second square-up (2) . .	8	12	96
Third square-up (3) . . .	6	12	72
Extra roof holes	2	10 & 8	18
Total.	36	...	408

The roof holes were drilled only when needed. In the new tunnel the heading holes proper, were :

DESIGNATION.	Number.	Depth, in feet.	Total, in feet.
Rib holes (R)	10	11	110
Relievers (Re)	18	11	198
Lifters (L)	8	11	88
Cut holes (C)	6	13	78
Total	42	...	474

Adding the 7 down-holes D used only when necessary to break down the top edge of the bench and drilled in the heading round, we have $7 \times 6 = 42$ feet, making the total footage 516 feet. In the old tunnel the bench drilling comprised 6 down-holes 12 to 13 feet deep, a total, say, of 72 feet, and 4 toe-holes 10 feet deep, making a grand total of 112 feet of bench drilling. In the new tunnel the bench drilling comprised 20 bench-holes 11 feet long and 5 toe-holes 5 feet long, or a total of 245 feet. Drilling rates cannot be compared with the records, as they are only partial for the old tunnel and incomplete for the new tunnel. Very little, too, has been told of the drill servicing at the old tunnel, but hand-sharpening was employed at an ordinary blacksmith forge and drill conditioning was a process of doing what was necessary only when it was necessary. In comparison, the servicing equipment at the new tunnel as shown by several views (figs. 5 and 6) stands out in sharp contrast.

Blasting performance like drill performance, and for the same reason, is not in condition for comparison. On the new tunnel, of course, electric firing and dynamite are being employed, with all the recent perfection of cartridges, explosives and electric blasting, and all the modern finesse of delay firing. On the old

Fig. 6. — Drill equipment train on new tunnel operated by electric locomotive. Nippers were important chaps in the old tunnel — every drill runner had one to fetch and carry its "steel". At new Masconnetcong drill servicing between shop and face is by train.

Fig. 5. — East portal drill and blacksmith shop on new tunnel.

On the old tunnel, says an account published in 1875, drills "were found to run for months with little or no repairing necessary". On the new tunnel all drills undergo regular conditioning.

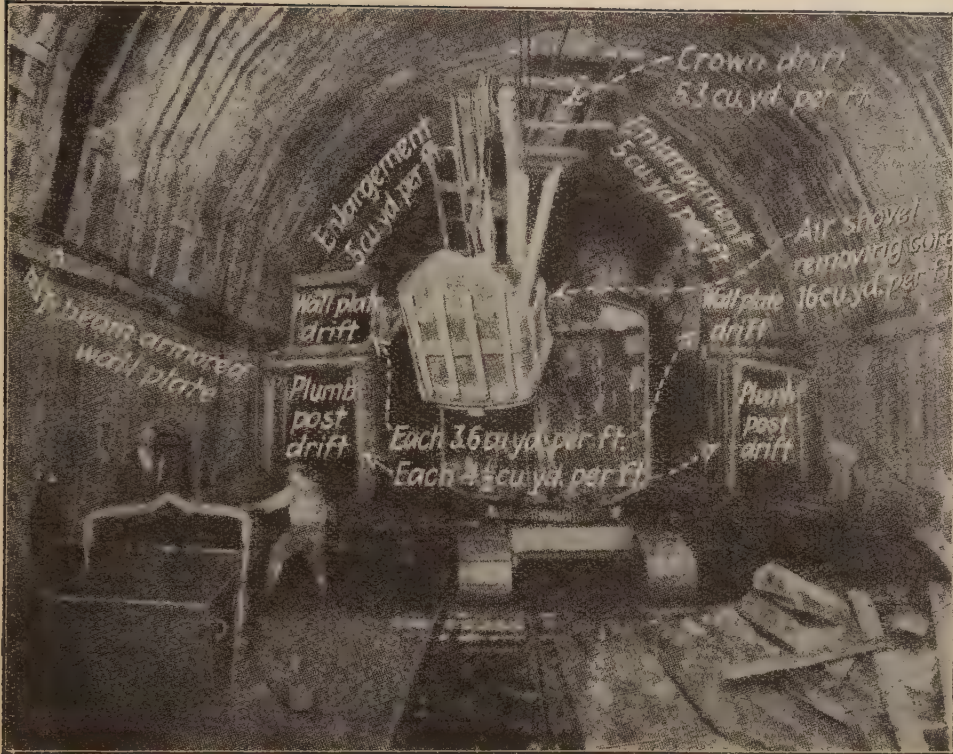


Fig. 7. — Power shovel excavating soft ground core, new tunnel.

This view shows the drifts, the core and the timbering where steel inner frames were not necessary.
The shovel is air-operated.

tunnel it is interesting, then, to note that dynamite and electric firing were used throughout for the first time in tunneling in America. So revolutionary was the practice that contemporary writings on the old tunnel work enter into elaborate argument defending it. Indeed, the accomplishment of dynamite at old Musconegcong deserves notice; for 82 000 cubic yards excavated the average was 1.71 lb. of dynamite per cubic yard.

Timbering and mucking. — Timbering was a particular problem in both tunnels in the soft ground and, to a less extent, in loose rock. In the seamy rock at the east end of the new tunnel where only

roof falls had to be guarded against, only a plain segmental timbering was required. The soft-ground problem was much more complex. The ground is very unstable when wet and in the new tunnel workings it developed enormous pressures. Comparable pressures in the old tunnel are not indicated by any of the contemporaneous accounts. Indeed, in the English system of timbering, used in that tunnel generally, all the timbering usually saved was saved, and only occasionally was it found impossible to pull the crown bars ahead. Either of these procedures would be virtually impossible with the pressures existing in the new tunnel workings. Here 16-inch fir seg-

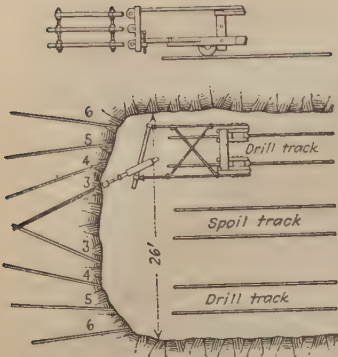


Fig. 8. — Drill carriage for heading holes in old tunnel.

These carriages, copied from the Hoosac tunnel carriages, were of timber with iron shaft bars. The contractor's mining superintendent, William White, who worked at Hoosac, designed them.

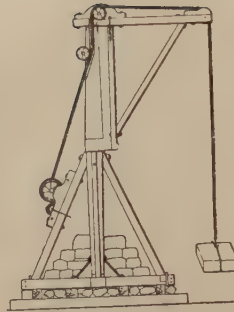


Fig. 9. — Hand derrick for lining old tunnel.

This appears to have been the only equipment besides regular masons' tools used in lining the old tunnel.

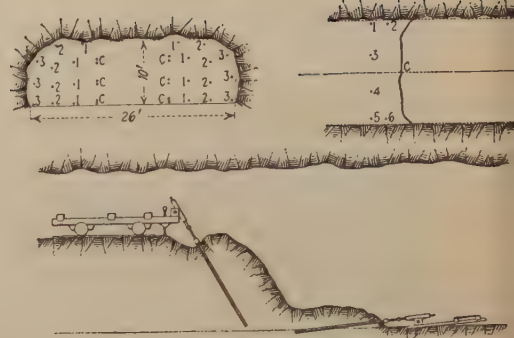


Fig. 10. — Heading hole diagram and bench cut carriages on old tunnel.

Note the wedge-shaped center cut. William White credited with having introduced the wedge center cut subsequent "squaring up" rounds at old Musconetcong.

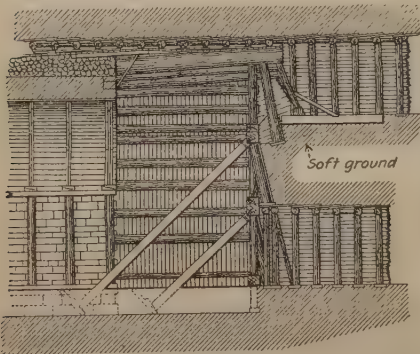


Fig. 11. — English system of timbering soft ground in old tunnel.

Short lengths of tunnel excavated and timbered to full section and then lined, in alternate operations, with a starting drift at the crown and a bottom drift for drainage and an additional point of attack, is the typical "English system" procedure.

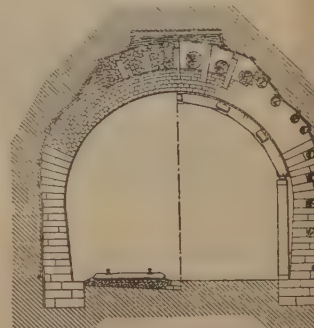


Fig. 12. — Lining for soft ground in old tunnel.

Coursed rubble stone side walls brick arch all set in Rosendale cement mortar. Compare with new tunnel lining.

ments set close were split and shattered, and 12-inch diameter posts were broken. The normal timbering is 12 x 12-inch posts and arch segments set close, increased to 12 x 16-inch posts and segments in heavier ground and in the worst places reinforced by an inner "timbering" of steel beam posts and segments as shown by accompanying drawings (fig. 15).

In the old tunnel the excavation and timbering followed very closely the typical English system, as the drawings make apparent. About 20 feet of tunnel was excavated to full cross-section and then it was lined; then another length was excavated and the lining was built. As stated before, the process involved no particular complications and apparently required no more than ordinary good care.

In planning the work through soft ground for the new operation it was thought best to drive a crown drift and two wall plate drifts, making enlargement from these drifts, then placing wall plates and segmental roof timber. A power shovel was then to be used to take out the center of the remaining core down to grade, leaving a bench on each side to support the wall plates. These benches were to be taken out as the plumb posts were erected. The pressures developed soon put a check on the planned procedure and the plan was changed to that shown by the drawings (fig. 16). This gave an opportunity for placing plumb posts, wall plates and bottom arch segments and bracing them against the core. The crown drift similarly gave opportunity for placing, and stulling to the core, the top crown bars. The drifts then left uncompleted timbering only at the haunches, which were then widened out right and left from the crown drift by placing one crown bar after another, stulling them to the core and driving polling-board lugging. Finally, under the crown bars and lagging the remaining arch segments were placed. All processes can be very clearly visualized from the drawings and views (figs. 13 to 18); scarcely a detail needs further explanation.

There are in the drifts and core about the following yardages of excavation :

DRIFTS.	Size, in feet.	Volume, cubic yards per foot.
Crown	12 1/2 × 11 1/2	5.3
Wall plate (two). . .	8 1/2 × 11 1/2	7.2
Plumb post (two) . .	11 1/2 × 10 1/2	9.0
Enlargement, both haunches . . . . .	...	10.0
Center core. . . . .	..	16.0
Total. . .	...	47.5

All but the core excavation is by hand,

the muck being taken out in small push cars, the cores being taken out by a 1 1/2-cubic yard capacity crawler-traction shovel equipped for air operation. Otherwise the earth mucking methods are like those of the east end in rock where the heaviest mucking has to be done. This core excavation by power shovel is the major distinction, in mucking methods in earth, between the old and the new tunnels.

In rock at the east end, the full excavation was handled by power shovel — the shovel used on the east approach cut changed to operate by compressed air. Two tracks were laid into the tunnel; the shovel was operated on one and the outgoing muck trains on the other. The incoming empty trains came into the tunnel on the shovel track, an air hoist on the rear of the shovel being used to shift the cars to the loading track. At the west end where a crawler-traction shovel is employed, the car shifting is done by gas and electric locomotives, but an improvised traveler carrying an air hoist will be installed. For handling the shovel excavation, the regular 5-cubic yard dump cars for the open-cut work were used. They were spotted by a 7-ton electric locomotive and hauled to and from the waste dumps by 16-ton gas locomotives.

Lining. — In the old tunnel, only the 770 feet from the west portal in through the soft ground and the 263 feet through loose rock were lined. The lining was masonry, coursed rubble walls and a brick arch. Figure 12 also indicates the type of arch centering employed. The mortar was 1 : 1, of Rosendale cement. Virtually the only equipment, besides masons' tools, used in lining work was the hand derrick illustrated (fig. 9). Two men, it is stated, could raise a ton block of stones with this derrick. That credit may go to an old-time contractor's superintendent, it is mentioned that the derrick was designed by Jacob Sny-

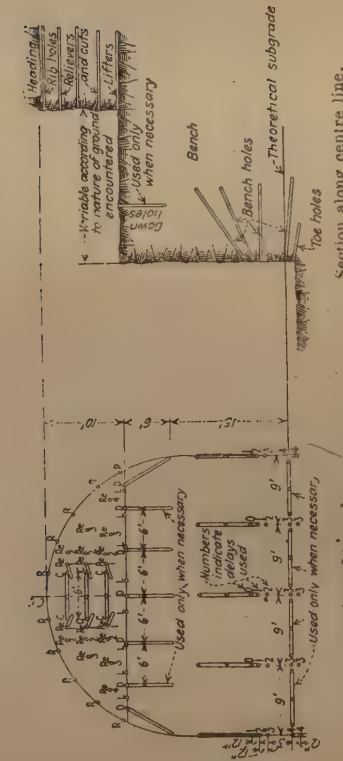


Fig. 13. — Drill hole diagram for complete round in new tunnel.

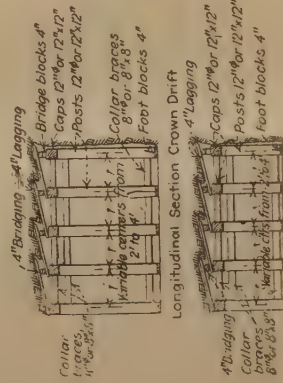


Fig. 14. — Lined section and timbering for moderate pressure, new tunnel.

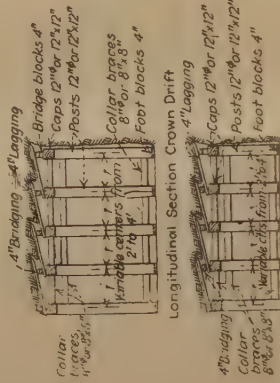


Fig. 15. — Steel "timbering" frames for very heavy ground, new tunnel.

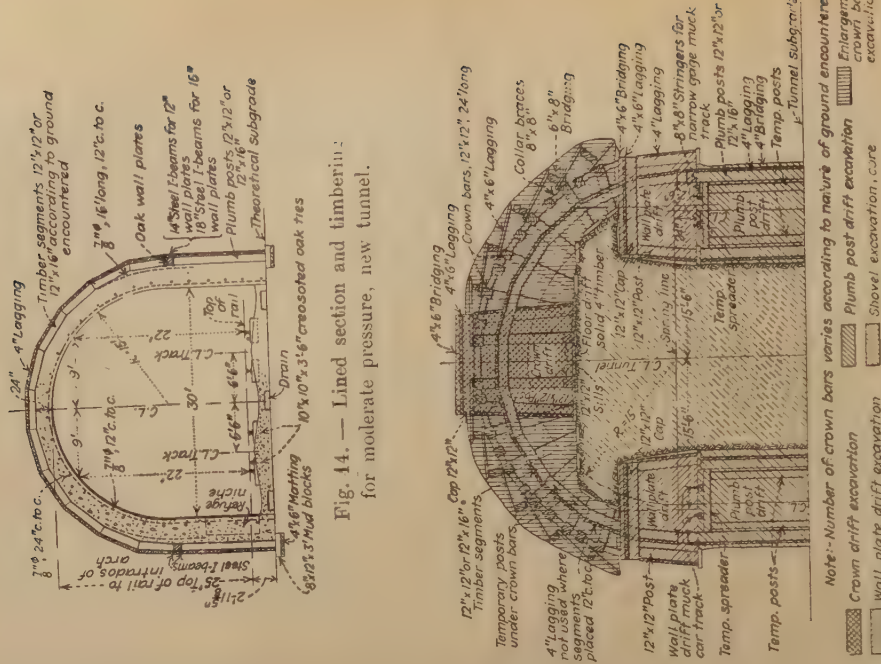


Fig. 16. — Drift and timber layout for soft ground, new tunnel.

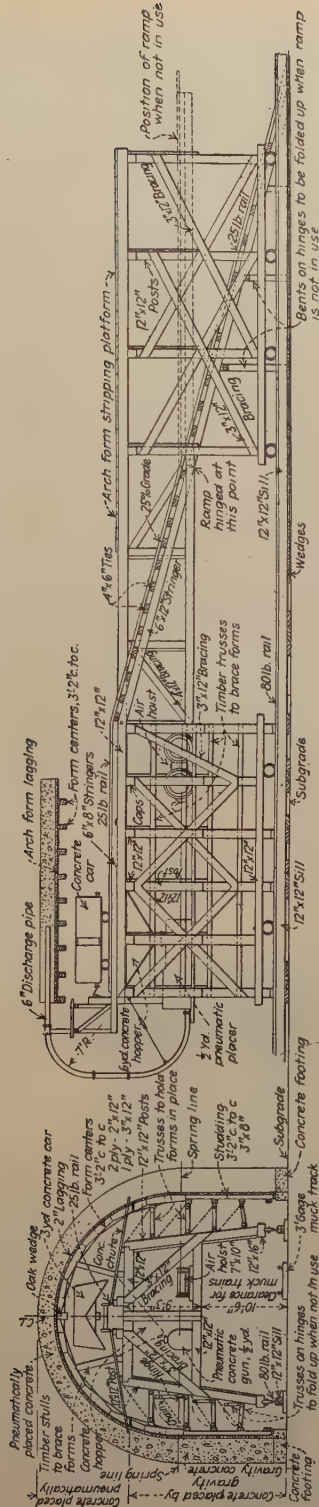


Fig. 17. — Lining traveler used on new tunnel.

der, a mason superintendent for Charles McFadden, the contractor.

The lining of the new tunnel is portland cement concrete, of which about 25 000 cubic yards will be required. Besides the concrete, some 2 500 000 ft.b.m. of timber and 550 tons of steel are required. In 1875, the year when the old Musconetcong tunnel was completed, David O. Saylor put the first American-made portland cement on the market. Probably not 15 000 barrels a year were produced for the next five years. As a considerable construction material, portland cement concrete has come into being since the first Musconetcong tunnel was completed; and by the same token all concrete-making machinery is new. We have, then, in mixing and placing plants for the new tunnel a type of equipment unthought-of when the old tunnel was lined. This equipment is shown clearly by the drawing and views (figs. 17 and 19).

The lining of the new tunnel is shown by several of the drawings (figs. 14-15), and the notable feature is the steel frames set inside the timbering in heavy ground and embedded in the concrete. Where the steel frames are not used the concrete lining is reinforced. The particular interest of the lining work lies in the mixing and placing plants, which are essentially alike at both ends. The arrangement is ordinary; derricks unload from cars into stock-pile or overhead steel batch-measuring bins; a 1-cubic yard cube mixer is under the bins and right- and left-gate batch cars on surface tracks take the concrete to the tunnel. A 1 : 2 : 4 concrete is used for lining.

The notable feature is the manner of placing the lining. Briefly, all but the crown section of the lining is placed by gravity from a traveler and the key section is placed pneumatically by a Ransome 14-foot pneumatic placer. The general arrangement of the traveler is shown by figure 17. Its functions and operation are amply explained by the

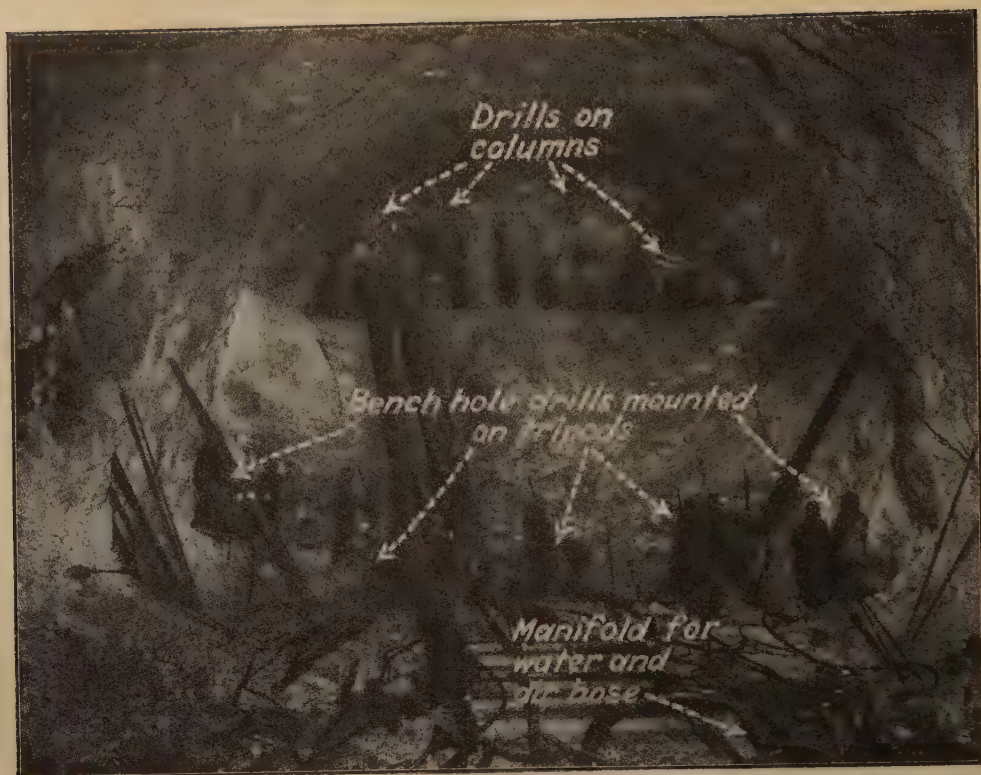


Fig. 18. — View of heading and bench in new tunnel.

Note the use of steel screw columns to which the drills are clamped by a universal column arm for drilling face holes. Drills were tripod-mounted for drilling bench holes.



Fig. 19. — Lining traveler and forms ready for operation.

This view is at the west end, and is interesting particularly for showing how the forms are braced from the traveler.

legends on the drawings. A traveler is installed in each end of the tunnel.

Direction and labor. — The direction of the old tunnel work included men whose names have since become known in engineering and contracting. Robert H. Sayre was chief engineer, Calvin C. Brodhead was principal assistant engineer, and Henry S. Drinker was resident engineer. The contractor was Charles McFadden of Philadelphia, Pa., who had regularly on the work about 1 000 men who lived, an old account says, in a « settlement of several hundred shanties on each side of the mountain ». The men were mostly Irish but at one time the contractor brought up some Virginia negroes and the resulting race riot set a record for pay-day battles — three negroes and one Irishman killed. It is told that « liquor shanties » gave considerable trouble on the old work. Today the contractor has a deputy-sheriff to keep boot-leggers off the job. The old work excelled the new in spectacular accidents — less than such going unnoted. Once a boiler blew up and killed three men and on two occasions quantities of the new explosives « went off », and killed no one.

The term shanties used above pro-

bably tells perfectly the kinds of laborers' camps at old Musconetcong. On the new work the contractor houses about 200 men at each end in substantial bunk houses heated and screened and having bathing facilities, and he has dining halls, camp stores, engineer's and contractor's offices, and all the usual services of a modern construction camp. The lighting is by electricity. Water is piped to sump and job and electric pumps are provided for fire pressures. Job service buildings are equally substantial and comprise sawmills, drill sharpening and blacksmith shops, and cement and store houses all modernly equipped. Aside from the improved construction equipment with which to work, probably no difference between the operations of 1874 and 1927 would appear more astounding to the workmen on the old tunnel than the living accommodations and commissary provided for their kind at the new tunnel.

The new tunnel is being built for the Lehigh Valley Railroad, G. T. Hand, chief engineer, and W. H. Ramsey, resident engineer on the work. The contractor is Bates & Rogers Construction Co., Chicago, Ill., with R. E. Ross, district manager in charge of the work.

MISCELLANEOUS INFORMATION

[628.143.2]

1. — Means for improving steel rails.

Figs. 1 to 6, p. 359.

(*The Metallurgist*, supplement to *The Engineer*).

The progressive increase of traffic has raised the demands placed on rail steel and has created the necessity for a harder material. This question is the subject of a recent article by Pilz ⁽¹⁾ in *Stahl und Eisen*. The article is described as Report No. 55 of the Rolling Mill Committee of the Verein Deutscher Eisenhüttenleute and consists of a review of methods of improving rail steel by means of chemical composition and by heat treatment of the rails, with special reference to the processes of Sandberg, Neuves-Maisons, Hütte-Ruhrort-Meiderich and Maximilianshütte. For the German State Railways elastic limit in compression of at least 45 kgr. and preferably 50 kgr. per square millimetre (28.57 and 31.74 English tons per square inch) is stated to be necessary for rail steel to carry engines of 25 tons axle weight.

Considering chemical composition first, attention is drawn to the fact that sufficient strength and greater toughness, giving increased resistance to wear, can be obtained by means of higher carbon content in conjunction with more silicon. Basic steel of this class has met requirements with an elastic limit of 42-46 kgr. per square millimetre (26.67-29.21 English tons per square inch) and tensile strength of 75-85 kgr. per square millimetre (47.62-53.97 English tons per square inch). Deliveries of this steel made to the German State Railways and the countries outside Germany are stated to have come up to expectations in every way. Reference is made to wear tests by rolling abrasion carried out by Canaris ⁽²⁾ on harder basic steel rails of this type and on heat-treated rails in which the former gave superior results. In this connection

Pilz observes that Meyer and Nehl ⁽³⁾ have found that a fine structure favours abrasion. Pilz lays considerable stress on the good behaviour of the harder basic steel rails referred to, and draws attention to the fact that considerable improvements have been made in the last few years in the manufacture of rails by the Thomas process and that the production of rails of this class in any quantity and economically is quite practicable. Of special steels 12-14 % manganese has been used, but does not appear to have given consistent results. No considerable use of this steel for rails has so far been made on the Continent. Both in America and Germany, however, manganese-silicon steel (Mn 1.5-2.0 %) has given good service. A relatively high elastic limit of the order of 52 kgr. per square millimetre (33.02 English tons per square inch) compared with tensile strength of 71-80 kgr. per square millimetre (45.08-50.80 English tons per square inch) is a feature of this steel. An increase of silicon up to 0.5 % with manganese up to 1.4 % has given good results.

With vanadium steels very good results in respect to high elastic limit and toughness have been obtained. Experiments at the August-Thyssen works on trial melts containing 0.23-0.28 % vanadium have given ratios of elastic limit to tensile strength up to 74 % for basic steel and 68 % for acid open-hearth steel, with mean tensile strengths of 85 kgr. and 90 kgr. per square millimetre (53.97 and 57.14 English tons per square inch) respectively.

Steels containing copper show satisfactory behaviour in regard to toughness, drop test and elongation, but no increase in elastic limit has

(1) PILZ, *Stahl und Eisen*, October, 1927.

(2) CANARIS, *Stahl und Eisen*, 45 (1925), p. 33.

(3) MEYER and NEHL, *Stahl und Eisen*, 44 (1924), p. 457.

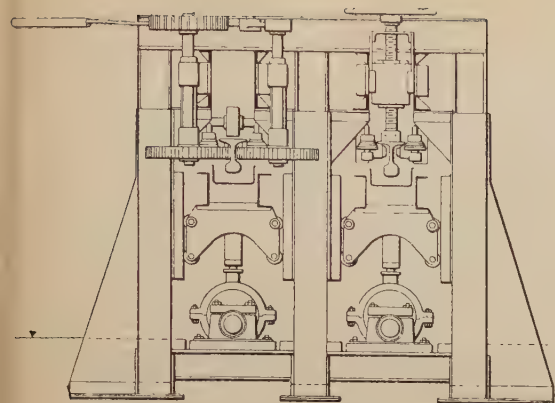


Fig. 1.

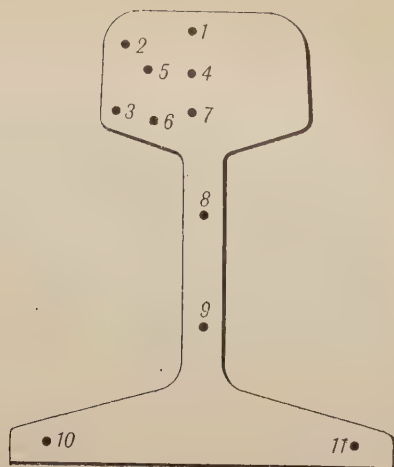


Fig. 2.

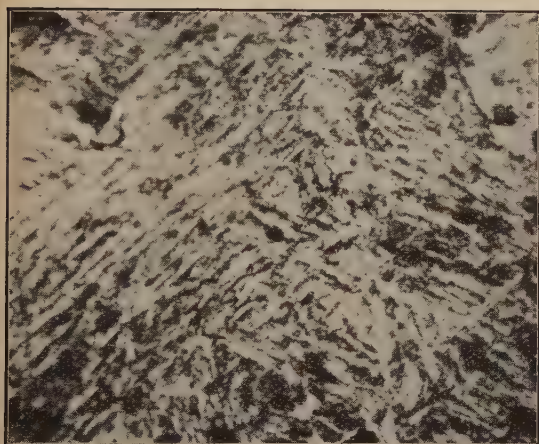


Fig. 3.

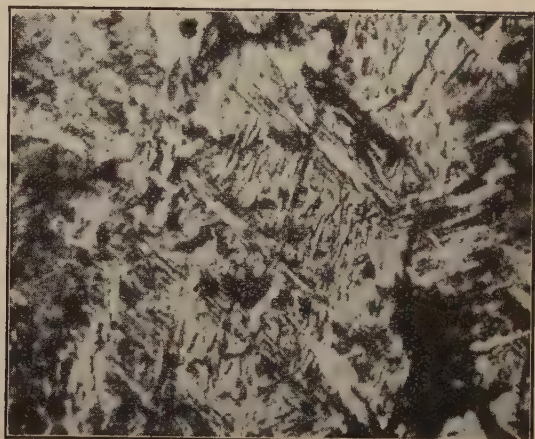


Fig. 4.

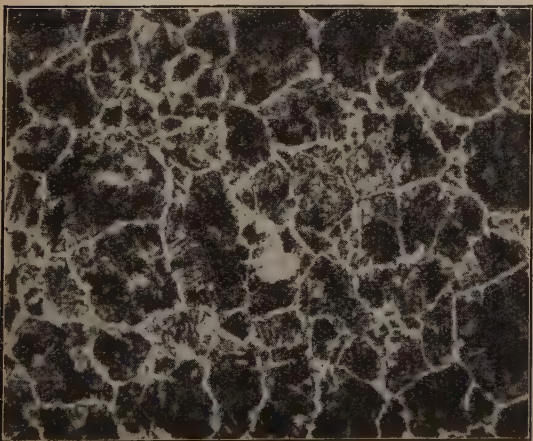


Fig. 5.

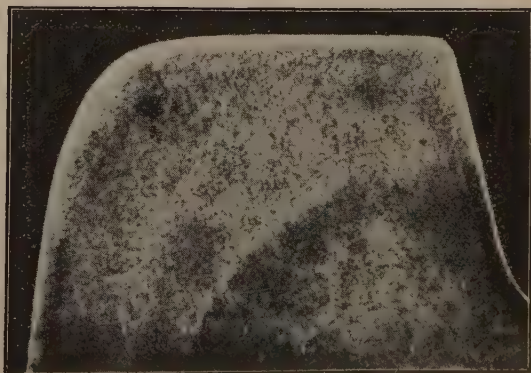


Fig. 6.

been observed nor improved wear as the result of adding copper to rail steel.

Turning to methods of improving properties by means of heat treatment, the Sandberg process is first described, as being the best known. The method of applying this process to rails at rolling temperatures, as they come from the rolls, employed at the Hagondange works in France and described by Marcotte and Martineau in *Revue de Métallurgie* this year, is described and discussed. An account of this process was given in *The Metallurgist* of July 1927.

Another process similar in principle has been employed at Neuves-Maisons for nearly three years. The rail is held upside down and the head submerged for a period in a certain volume of cold water contained in a bosh which is raised and lowered under it. The apparatus is shown in figure 1. The rail runs into it and is held by the rollers during treatment. Pilz criticises this process on the grounds of speed of opera-

tion, and questions whether heat treatment by this method can keep pace with output of rails under modern conditions of mass production from large ingots.

Two other works which are trying heat treatment of rails in Germany are Die Vereinigten Stahlwerke A.-G.-Hütte Ruhrort-Meiderich, and the Eisenwerks Gesellschaft Maximilianshütte at Rosenberg (Oberpfalz). At the former works tramway rails only are being treated. At the latter works, dealing with railway rails, patents have been applied for to cover the heat treatment process, which consists of a simple quenching of the rail head in water with subsequent tempering. Tests on a section of a treated rail submitted by this firm are described by Pilz. The composition was normal, viz., C, 0.42; Si, 0.17; Mn, 0.95; P, 0.055; S, 0.048 %. Brinell hardness numbers and corresponding tensile strength values at the points indicated in figure 2 are given in the table.

Hardness tests on a section of a rail treated by the Maximilianshütte process, at the points indicated in figure 2.

Brinell hardness number.		Corresponding tensile strength.					
		125.0 kgr. per square millim. (79.37 English tons per square inch).					
1 . . .	379.6	131.0	—	—	(83.17	—	—)
2 . . .	397.8	131.0	—	—	(85.72	—	—)
3 . . .	410.8	135.0	—	—	(59.94	—	—)
4 . . .	286.0	94.4	—	—	(61.91	—	—)
5 . . .	295.5	97.5	—	—	(57.59	—	—)
6 . . .	274.8	90.7	—	—	(52.45	—	—)
7 . . .	250.4	82.6	—	—	(39.94	—	—)
8 . . .	190.7	62.9	—	—	(41.08	—	—)
9 . . .	196.7	64.7	—	—	(39.75	—	—)
10 . . .	189.8	62.6	—	—	(39.37	—	—)
11 . . .	188.0	62.0	—	—			

The degree of hardness reached greatly exceeds that reported by Marcotte and Martineau for rails heat treated at Hagondange by the Sandberg process. At the hardest parts near the surface a martensite-troostite structure was found, indicating severe hardening. Even 1 inch below the tread, needles of martensite were observed. Photomicrographs illustrating this feature as given by Pilz are reproduced in figure 3 (structure near the surface) and figure 4 (internal structure) at 500 diameters. At the junction of head and web no martensite was observed, but mainly troostite. The steel appeared very

free from surface defects of the nature of longitudinal flaws, which Pilz attributes largely to the satisfactorily high rolling temperature employed, evidenced by the structure reproduced in figure 5 at 50 diameters. The depth of hardening is indicated in figure 6. Rails treated by this process, delivered to the Bavarian State Railways, have been satisfactorily reported on by a technical committee of inspection after six months' service.

In connection with the satisfactory behaviour claimed for these severely hardened rails, experience described by Marcotte and Martineau in

connection with the treatment of tramway rails is of interest. Flaking of the hardened tread is referred to. Investigation led to the conclusion that the chief causes were too severe hardening in conjunction with high carbon content (0.75-0.87 %). In these circumstances the volume change accompanying the structural change from ferrite-pearlite to martensite becomes excessive and produces severe stresses which cause internal fissures. By standardising a method giving less drastic hardening, trouble from flaking was overcome even in the higher carbon rails referred to above. It is to be noted, however, that the carbon content of the rail treated at Rosenberg, described by Pilz, is very much lower than that above referred to.

In conclusion, Pilz points out that with increase in resistance to wear of the rails the effect on wheel tires must not be forgotten and that the harder rails must be expected to increase the rate of wear of tires.

In a discussion of the report, Mettegang, of

the Ruhrort works, stated that they had been engaged in heat treatment of tramway rails since before the war. They had recently improved their process and had supplied a large number of treated rails to tramways in Germany and abroad. An appreciable difference between their process and those at Hagondange and Neuves-Maisons lay in their method of quenching and in the fact that the rails were not clamped or constrained in any way during quenching, which was applied to the head only.

Carpenter, in the James Forrest Lecture, delivered before the Institution of Civil Engineers in May 1927, directed attention to the value of heat treatment in improving the behaviour of rails in service. He referred to service trials in America, where in one case sorbitic rails have shown a 150 % increased life over untreated on a curve subjected to heavy traffic, and also conspicuous superiority at joints. In this country several of the largest tramway undertakings have adopted heat-treated rails as their standard. and trials of railway rails are in progress.

[385. (09.1 (.6) & 625 .176 (.6)]

2. — African railways and gauges.

Fig. 7, p. 362.

(*The Railway Engineer.*)

By arrangement with our weekly contemporary, *The Railway Gazette*, we publish (fig. 7) a railway map of Africa, drawn to scale, showing the lengths of the various systems. The map indicates the location of some 38 000 route-miles of line spread unequally over a country three times as large as Europe, or 100 times the size of England and Wales. On an equal basis for

miles of railway per 100 square miles of area as this country, Africa would have more than three times the present total for the world! Such a comparison — unfair though it is — clearly shows the great difference in conditions. A contrast with other new countries, such as South America and Australia, is, perhaps, more illuminating, and is given in the following table:

	Area.	Population.	Railway mileage.	Miles of railway per 100 square miles.	Miles of railway per 10 000 inhabitants.
Africa	11 500 000	143 000 000	38 000	0.33	2.66
South America	7 250 000	70 000 000	57 000	0.78	8.14
Australia	2 974 581	6 000 000	27 000	0.90	45.00

MAP OF AFRICAN RAILWAY SYSTEMS.

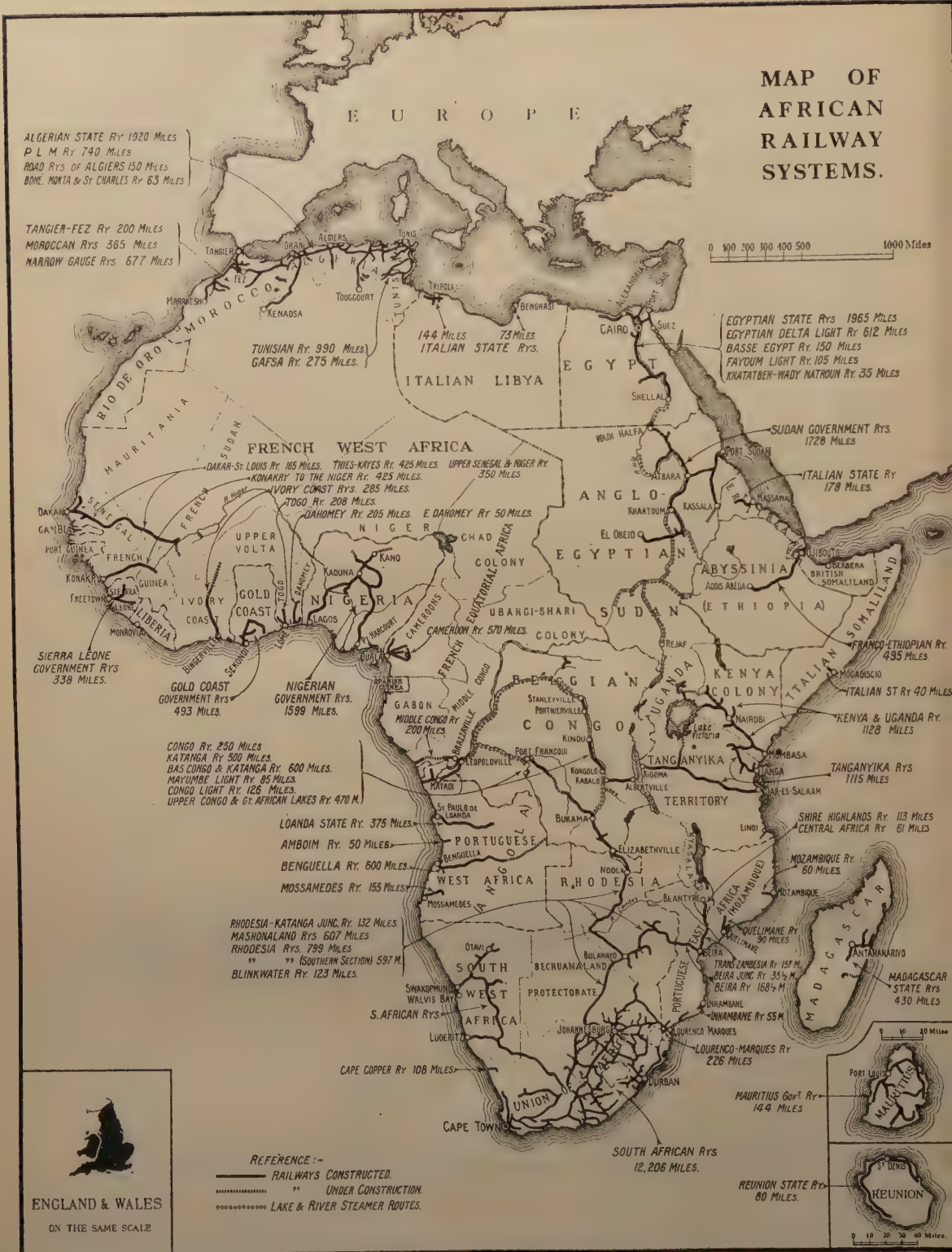


Fig. 7.

The map (fig. 7) does not distinguish between the various gauges, and the accompanying table is, therefore, published to give this information :

Railways of Africa, showing mileage on various gauges.

TERRITORY.	Total mileage.	4 ft. 8 1/2 in.	3 ft. 6 in.	Metre (3 ft. 3 3/8 in.)	2 ft. 6 in.	2 feet.
Union of South Africa.	12 624	...	11 639	...	...	985
Algeria	2 873	1 540	920	378	...	35
Egypt	2 775	1 740	...	155	880	...
French West Africa (1)	2 108	...	...	2 108	...	...
Rhodesia	1 870	...	1 870	...	...	...
Belgian Congo.	1 860	...	910	470	250	220
Sudan	1 728	...	1 728	...	...	...
Nigeria	1 599	...	1 466	...	133	...
Morocco.	1 432	415	...	77	...	940
Tunisia	1 265	317	...	948	...	...
Kenya and Uganda	1 128	...	...	1 128	...	...
Tanganyika	1 115	...	...	1 055	...	60
Angola.	1 025	...	500	320	...	205
French Equatorial Africa	670	...	...	570	...	100
Mozambique.	626	...	566	...	...	60
Gold Coast.	500	...	490	...	10	...
Abyssinia	495	...	...	495	...	...
Madagascar	430	...	...	430	...	...
Italian Zones	405	...	...	405	...	...
Bechuanaland	394	...	394	...	...	...
Sierra Leone.	338	...	...	...	338	...
Nyasaland	332	...	332	...	...	...
Mauritius	144	120	...	...	24	...
Spanish Zones	140	...	...	75	...	65
Reunion.	80	...	...	80	...	...
Total.	37 956	4 132	20 825	8 694	1 635	2 670

(1) Includes Senegal, Guinea, Ivory Coast, Togo, Dahomey, etc.

Great Britain, France, Belgium, Portugal, Italy and Spain are interested in the railways of Africa. Britain is first with about 22 000 miles, and France a good second with 8 000 miles, Italy and Spain, on the other hand, having only a small mileage. Of the 38 000 miles of railway

in Africa nearly 21 000 miles, or 55 %, are on the 3-ft. 6-in. gauge, with 8 700 miles, or 22 %, on the metre (3 ft. 3 3/8 in.) gauge. The 4-ft. 8 1/2 in. gauge accounts for 4 100 miles, or 11 %, and the 2-ft. 6-in. and 2-foot gauges, with 1 635 and 2 670 miles, divide the balance. While there

would thus appear to be a great diversity of gauges, this is more apparent than real, as the British standard gauge, except for the 120 miles in Mauritius, is concentrated in Egypt, Tunisia, Algeria and Morocco, and the 2-foot comprises two big systems in South Africa and in Morocco, the latter having been developed from light lines originally laid down for military purposes. All Southern Africa may be said to be 3-ft 6-in. gauge, while the metre gauge is the standard for most of the east and west coast systems, in addition to a large mileage in Tunisia. It is noteworthy that the 4-ft. 8 1/2-in. is the widest gauge adopted, this contrasting with South America's 5-ft. 6-in. and Australia's 5-ft. 3-in. The distribution of gauges between the various countries renders the provision of international links a relatively simple matter, and there can be little doubt that there will be a great deal of development in this direction. Most of the lines concerned in the Cape to Cairo route are on the 3-ft. 6-in. gauge, which, incidentally, provides the only link between east and west coasts — in South Africa — and the same gauge is used on the Benguela, Katanga and Rhodesian systems that will soon form the first international transcontinental railway.

The largest railway system in the country is, of course, that owned and operated by the Union of South Africa. That system of 12 206 miles, or, roughly, one-third of the total railway mileage of the continent, is noteworthy for its modern organisation, methods and equipment. Railway construction in South Africa commenced in 1859, when the first sod was turned of a private 4-ft. 8 1/2-in. gauge line designed to connect Cape Town, Stellenbosch and Wellington. This line, however, was not completed until 1863, but meantime — in 1860 — a 2-mile railway on the same gauge, between the Point and Durban, was opened to public traffic. Natal, therefore, has the credit for completing the first line of railway in South Africa. In 1870 there were only 69 miles of railway in service, 63 in Cape Colony and 6 in Natal, and then came the discovery of the diamond fields and the beginning of the development of the interior. In 1873 the Cape Government took over the private railways as a State undertaking, and Natal followed suit in 1877, the 4-ft. 8 1/2-in. gauge being discarded

and 3-ft. 6-in. substituted in 1881. Following the war, the railways of the Transvaal and the Orange Free State came under British influence, and when hostilities ceased in 1902 there were three separate railway organisations, with a combined mileage of 4 895. Extensive developments followed, and in 1910, when the systems in the British possessions were amalgamated, the mileage taken over by the Union Government was 7 041, the capital expenditure on the railways and harbours then amounting to £87 263 366. Within 10 years the State-owned mileage had increased to 9 600 miles, or 36 % in 10 years. The 1 331 miles of railways in South-West Africa have since been incorporated in the Union system, which now comprises 12 206 miles of line, and operates a further 418 miles of private lines.

Just as the size of the African systems differs as between the Union of South Africa with 12 624 route-miles and Sierra Leone with 338 miles, so conditions vary between wide limits. In some parts the country is absolute desert, in others it is of a mountainous character. Some territories are always short of water and others have an abundance through the great rivers. As a result, railway construction is hindered on the one hand by sand and dust storms, and on the other owing to the very swampy nature of enormous areas. Then there are great climatic differences, while traffic characteristics in the varying districts also have an influence on railway practice.

As is usual in new countries, the railways of Africa first developed as long single lines running out into the interior from suitable bases on the coast, this tendency being clearly illustrated in the map. Then branches were added to the main line, and as traffic developed following the provision of railway facilities came the need for connecting up the disconnected lines. That, broadly, is the position in Africa to-day. In the north and south a great deal has been done, but both east, west and centre the lines are extremely localised, and a large mileage of new railway will be required to bridge the gaps.

Some of the systems have been developed to a high degree of efficiency, especially when viewed from the standpoint of the conditions under

which they have to work, and every effort is being made to raise their standard of efficiency. The relocation of lines and the improvement of operating conditions by means of re-grading and the flattening of curves are improvement works

proceeding hand in hand with the employment of stronger track materials, more powerful locomotives and high-capacity rolling-stock, and as a result adequate facilities are being provided to meet the increasing traffic demands.

[385. (01 (.6)]

3. — The proposed Trans-Saharan railway.

Fig. 8, p. 366.

(*The Railway Gazette.*)

For over fifty years French engineers have studied means for piercing the great Saharan desert with a railway which would link French Algeria with French West Africa — the Mediterranean with the Niger — and so shorten a journey which occupies between 20 and 30 days into one of 5 days. In order now to reach the centre of the largest of all French colonies it is necessary to take a steamer from Marseilles to Dakar in Senegal (10 days), then a train from Dakar to Koulikoro (3 days), and lastly, a river boat from Koulikoro to Timbuctoo, or Tosaye or Bourem, which lie on the top of the great northern sweep which the Niger makes, before turning south-east in order to make its way through Nigeria to the ocean — and that river trip takes 8 days under the best conditions. But if a railway could be built from Bourem to the Algerian frontier, there to connect with the Algerian system, Marseilles could be reached in five days — three on the train and two on the Mediterranean. If, furthermore, an east-to-west railway could be constructed to link the Niger with Lake Chad, and so with the Congo, by its tributary the Oubangui, on which lies Bangui, in French Equatorial Africa, the latter would be brought within 3 800 miles of the Algerian ports and eight days' journey of London or Antwerp.

Advantages of the line.

Such a system, the French contend, would provide the most direct route from Europe to the Belgian Congo and thus to British-South Africa, especially as by the time of its completion it is reasonable to suppose that the Belgians would have connected the Oubangui

with Katanga by rail. It would sooner or later be connected with the rail systems in Portuguese Angola and British East and West African possessions, besides the Sudan and Egypt, while westward it would have its natural issue on the Atlantic at Dakar over the Dakar-Kayes line. The French Trans-African railway would thus become the spinal column of the whole African system, with its vital link with Europe in the Trans-Saharan. That is the reason why all studies of the Trans-Saharan line have enforced the idea that its route must be such as to permit a prolongation towards Lake Chad and the Congo Basin. Its rôle must be not merely French but international.

Recent developments.

Into the long history of the campaign for the Trans-Saharan railway it is needless to enter here, except to say that, following the massacre of the Flatters mission near Hoggar, in 1881, the project suffered complete neglect on the part of the authorities for many years thereafter. The campaign was left to private initiative, which equipped and sent out several expeditions and, finally, after the war, succeeded once again in enlisting the interest of the French Government. The war had taught France the need of rapid and safe communications with that reservoir of men and material which French Africa represents, and in 1922-1923 a Commission appointed by the *Conseil Supérieur de la Défense Nationale* studied the whole question. As the result of these studies the Council finally reported in favour of a Trans-Saharan line. That was in 1923, and



Fig. 8. — Map of North West Africa, showing route of projected Trans-Saharan railway, which would be 1 600 miles in length.

had not the financial crisis supervened, it is probable that the Government would have taken action. It was again left to private enterprise to pursue the campaign, and in this connection the expeditions across the Sahara by automobile will be recalled, the latest being the three Algerian missions which started November 1926 from Algiers, Constantine and Oran, and proceeded from the southernmost termini of the railways in these three departments to Bourem in six-wheeled cars. The most recent chapter in the history of the project is a proposal by the Minister of Public Works to insert in the 1928 budget an authorisation

for carrying the study of the line to a definite conclusion within three years — a proposal which Mr. Poincaré has rejected on grounds of economy, though it is hoped that he may be induced to reconsider his decision. Among the most fervent supporters of the scheme is Mr. Mahieu, Senator and President of the Supreme Railway Council, who declares that technically it presents no insurmountable difficulty, financially it does not exceed France's capacity, especially if recourse is had to German Reparations in kind, and economically it must ensure rapid development of French Africa. From the point of view of national

defence it has an equally ardent advocate in the Supreme Council of National Defence.

Question of route.

While the three Departments of Algeria dispute the honour of having the starting-point of the Trans-Saharan line, it is fairly certain that Oran will win in the end. From Colomb-Bechar, the present Oran railhead, the motor-car expedition of November 1926 reached Bourem on the Niger in just over seven days and made the return journey in less than five, while another expedition (the Estienne), adopting a shorter and straighter route, accomplished it in less than three. This latter route has been found practicable for the laying of rails because it is free from sand dunes and shifting sand. It is asserted, indeed that along the greater portion of it and all through the desert proper no bridges, cuttings, etc., would be necessary. The lack of water had seemed until recently and insuperable obstacle, but the new semi-Diesel internal-combustion motor, capable of consuming vegetable oils, such as abound in the Niger district, seems likely to remove it. This motor needs little water and renders it possible to cover long distances (up to 350 miles) without a stop. Thus the stations need be few and the personnel reduced to a minimum. Moreover, high speeds can be maintained, and as the distance between Colomb-Bechar and Bourem is about 1 200 miles, that is an important point. At Bourem the Niger can be bridged with comparative ease, and the line thus carried south to Ouagadougou, the capital of the Upper-Volta colony, a distance of some 400 miles. Here is the prospective rail centre of French West Africa.

Estimated cost of proposed line.

As regards expenditure, it was calculated in 1923 at 500 000 fr. per kilometre (804 500 fr. per mile), which would make a total outlay of 1 600 000 000 fr., involving an annual payment in interest of 128 000 000 fr. Allowance must be made for fluctuations of exchange rates and prices since then, but it is asserted that half the charges could be earned by the operation of the railway in the earlier years.

It is suggested, further, that the concessionaire company might be allowed certain privileges, such as industrial or sales monopolies or territorial grants, after the fashion in which the American transcontinental lines were built, and, finally, as already mentioned, recourse might be had to German manufacturers of railway material under the system of Reparations in kind. But in any event the expenditure cannot be considered excessive in face of the wealth which it would produce. In French Sudan alone there are to-day 150 000 000 acres of unsaleable land. If they could be made to value 1 000 fr. per acre, as has been done in Morocco, could not a portion of this new-found wealth be devoted to paying off the cost of construction and maintenance of the Trans-Saharan line? The time required for construction has been put at seven to eight years, but could certainly be made considerably less.

There is also the question of safety. The Sahara is pacified, but incursions are possible from three directions. One is the Talifet, in Southern Morocco, which must sooner or later be reduced by the French army. The second is the Spanish strip of coast on the Atlantic known as the Rio del Oro, the interior of which has never been subjugated. The third is the hinterland of Italian Tripolitaine. By efficient policing on the part of the Algerian Government, and the security which the railway itself carries with it, these dangers, which are not considered serious, can be removed.

Traffic possibilities.

Opponents of the Trans-Saharan scheme have argued that not a single traveller nor a single ton of merchandise would be diverted to it from the sea route, and that in any case no heavy goods could afford to pay the costs of transport by rail over 2 000 miles. But the journey from Ouagadougou by rail to the port of Grand Bassam, on the Ivory Coast (most of this line has yet to be built), and thence by steamer to Bordeaux must occupy 18 days, whereas that by the Trans-Saharan route would occupy six. And as for goods traffic, the question of time is vital in the case of

some merchandise, while even in that of heavy material the low cost of production in French West Africa should compensate the excess in costs of rail over sea transport. Thus frozen meat, butter, eggs, fruits and other perishable goods are reckoned on for an annual tonnage of 80 000. But there are vast possibilities in the Niger and Upper Sudan for the production of cotton, rice, wheat, maize, vegetable oils, leather, wool, etc., and part of such produce could be relied on to take the Saharan route. In the north-to-south direction, via the

Sahara, there should be opportunity for the carriage of dates, wines, sugar, salt, and all kinds of manufactures. All things considered, it is calculated that from the outset the Trans-Saharan should be transporting annually 80 000 passengers and 300 000 tons of goods. The possibility of discovery of mineral wealth in the desert and the Niger country must not be excluded, and consideration must be given to the certain development of the known mineral deposits in the southern portion of the Oran Department.
